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## Overview

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The Thermal and Fluids Analysis Workshop (TFAWS) is an annual NASA-sponsored training and professional development workshop to advance the science and technology for thermal and fluid physics analysis. Its purpose is to encourage knowledge sharing, professional development, and networking throughout the thermal and fluids engineering community as well as the aerospace community at large. To this end, it offers activities that suite engineers at all levels of experience including new hires and students. The vision of TFAWS is to maintain continuity across time, and centers as well as between disciplines (passive thermal, active thermal, aero-thermal, etc). Annual sharing of knowledge allows engineers to be current with lessons learned. The inter-center nature of the conference helps ensure knowledge sharing across the agency. It also helps minimize overlaps and duplications across centers. TFAWS provides a tremendous opportunity for enhancing collaboration between NASA centers, with other government agencies, industry, academia, and international thermal and fluids science community. TFAWS is planned by a cross-agency steering committee and the hosting duties rotate to a different center each year. Marshall Space Flight Center is proud to be hosting TFAWS 2017.

This year, the conference will be held at The Westin Huntsville. TFAWS 2017 consists of five parallel sessions. Of the five training sessions, two are hands-on software training provided by various software vendors. One session is dedicated to theoretical course presentations, and the final session consists of software demonstrations and group meetings.

The paper presentation session provides the opportunity for those in the thermal-fluids community to present their work to their peers. This allows for greater dissemination of this material within the community as well as provides a valuable forum for discussion about its applicability to other advancements within the various disciplines. The paper session is split into four categories based on the general focus for each topic area: Active Thermal/Fluids & Life Support, Passive Thermal, Aero-thermal, and Interdisciplinary. Plenary talks will be presented at lunchtime along with a keynote talk at the banquet. Finally, hardware and software vendors will provide information to the attendees at tables/booths.

## TFAWS Agenda 2017

**Monday, August 21, 2017**

Time	Med I	Med II	Med V	Med VI	Venice I
8:00 AM	Thermal Analysis Results Processor (TARP)	Introduction to TSS		Active Thermal Paper Session I	
9:00 AM			MLI Demo		
10:00 AM					
11:00 AM					
12:00 PM	Enjoy Bridge Street Town Centre for Lunch				
1:00 PM	Step Out to View Partial Eclipse				
2:00 PM	COVeR: Capture Output and Verify Results	Introduction to TSS			OPENFOAM Demo
3:00 PM			STAMP Demo		
4:00 PM					Loadpath Veritrek Demo
5:00 PM	Adjourn				
Evening	TFAWS 2017 Welcome Reception at Bar Louie				

# TFAWS Agenda 2017

**Tuesday, August 22, 2017**

Time	Med I	Med II	Med V	Med VI	Venice I	Other
8:00 AM	Intro to RadCAD®	Advanced TSS	Passive Thermal Paper Session I		SLS Thermal Panel (ITAR)	
9:00 AM				CAD-Embedded CFD (FloEFD)		
10:00 AM				ThermoAnalytics Tutorial/Software Demo		
11:00 AM						
12:00 PM	Lunchtime Speakers (Mediterranean III/IV) Garry Lyles, Space Launch System Program Chief Engineer					
1:00 PM	Siemens PLM Simcenter3D Thermal and Flow	Advanced TSS	Interdisciplinary Paper Session I	GT-SUITE Multi-Physics Overview		MSFC Center Tour
2:00 PM	Loadpath Veritrek			Two-Phase Cryo Prop Modeling		
3:00 PM						
4:00 PM				Tecplot 360 Demo		
5:00 PM	Adjourn					
5:30-7:00 PM					TFAWS Delegates Meeting (Invite Only)	
Evening	Pints and Pixels, Monaco					

## TFAWS Agenda 2017

**Wednesday, August 23, 2017**

Time	Med I	Med II	Med V	Med VI	Venice I
8:00 AM	Introduction to C&R Thermal Desktop® and FloCAD®	GT-SUITE for Thermal Fluids and Multi-Physics Workshop		Active Thermal Paper Session II	Passive Thermal TDT (Invite Only)
9:00 AM			TSS Demo		
10:00 AM					
11:00 AM			IR Demo		
12:00 PM	Lunchtime Speaker (Mediterranean III/IV) Les Johnson, Technical Assistant Advanced Concepts Office				
1:00 PM	CAD-Embedded CFD Workshop (Using FloEFD)	Winplot Session 1	Fundamentals of Ablative Thermal Protection Materials	Interdisciplinary Paper Session II	Active Thermal TDT (NASA Civil Servant Only)
2:00 PM					
3:00 PM					
4:00 PM	Student Poster Session (Mediterranean III/IV)				
5:00 PM	Adjourn				
Evening	TFAWS 2017 Banquet at USSRC Davidson Center Keynote Speaker: Dr. Tom Crouch				

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## TFAWS Agenda 2017

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**Thursday, August 24, 2017**

Time	Med I	Med II	Med V	Med VI	Venue I
8:00 AM	COMSOL Multiphysics for Thermal and Fluid Analysis	Siemens PLM Simcenter3D Space Systems Thermal	Cryogenic Fluid Management	Introduction to On Orbit Thermal Environments	ITAR Paper Session
9:00 AM					
10:00 AM					
11:00 AM					
12:00 PM	Lunchtime Speaker (Mediterranean III/IV) Graham Nelson, Liquid Propulsion Systems Additive Manufacturing				
1:00 PM	Introduction to CRTech TD Direct®	Introduction to GFSSP	Future of NASA Aerosciences	Environmental Control and Life Support Systems 101 Course	Active Thermal Paper Session II
2:00 PM					
3:00 PM					
4:00 PM					
5:00 PM	Adjourn				
Evening	Campus 805 Greenway, NASA Center Cornhole Competition				

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## TFAWS Agenda 2017

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**Friday, August 25, 2017**

Time	Med I	Med II	Med V	Med VI	Other
8:00 AM			Aerothermal Paper Session		MSFC Center Tour
9:00 AM	Winplot Session 2			New and Advanced Features in Thermal Desktop	
10:00 AM					
11:00 AM					
12:00 PM	Adjourn. Thank you for being part of TFAWS 2017!				

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## **TFAWS 2017 Host Center**

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### **Marshall Space Flight Center**

For more than 50 years, the unique capabilities and expertise at NASA's Marshall Space Flight Center has been used to design and build the engines, vehicles, space systems, instruments and science payloads that make possible unprecedented missions of science and discovery throughout our solar system. Marshall's rich history of engineering excellence enabled the development of the Saturn Program that put man on the moon, developed new rocket engines and tanks for the Space Shuttle Program, built sections of the International Space Station and now manages all the science work of the astronauts aboard the ISS from a 24/7 Payload Operations and Integration Center. As one of NASA's largest field centers with nearly 6,000 civil service and contractor employees, Marshall Space Flight Center is leading the development of the Space Launch System, the most powerful rocket ever designed to carry human explorers, their equipment and science payloads deeper into space than ever before.

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## **TFAWS 2017 Conference Information**

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During TFAWS 2017 there will be an information booth setup in the lobby of The Westin with TFAWS staff members available to answer any questions about the conference or Huntsville in general. The booth will be staffed from 8AM – 5PM daily. Provided in your TFAWS Welcome Bags are an assortment of brochures and maps of Huntsville and the surrounding area as well as activities and restaurant guides.



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## TFAWS 2017 Hotel Information

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TFAWS 2017 will be held at The Westin Huntsville, conveniently located in Bridge Street Town Centre which features over 70 upscale shops and full-service restaurants, the 210-room Westin Huntsville Hotel, and the 14-screen Monaco Pictures. The Westin Huntsville offers over 13,000 square feet of handsomely appointed meeting space within minutes of Marshall Space Flight Center, Huntsville International Airport, and the U.S. Space and Rocket Center.

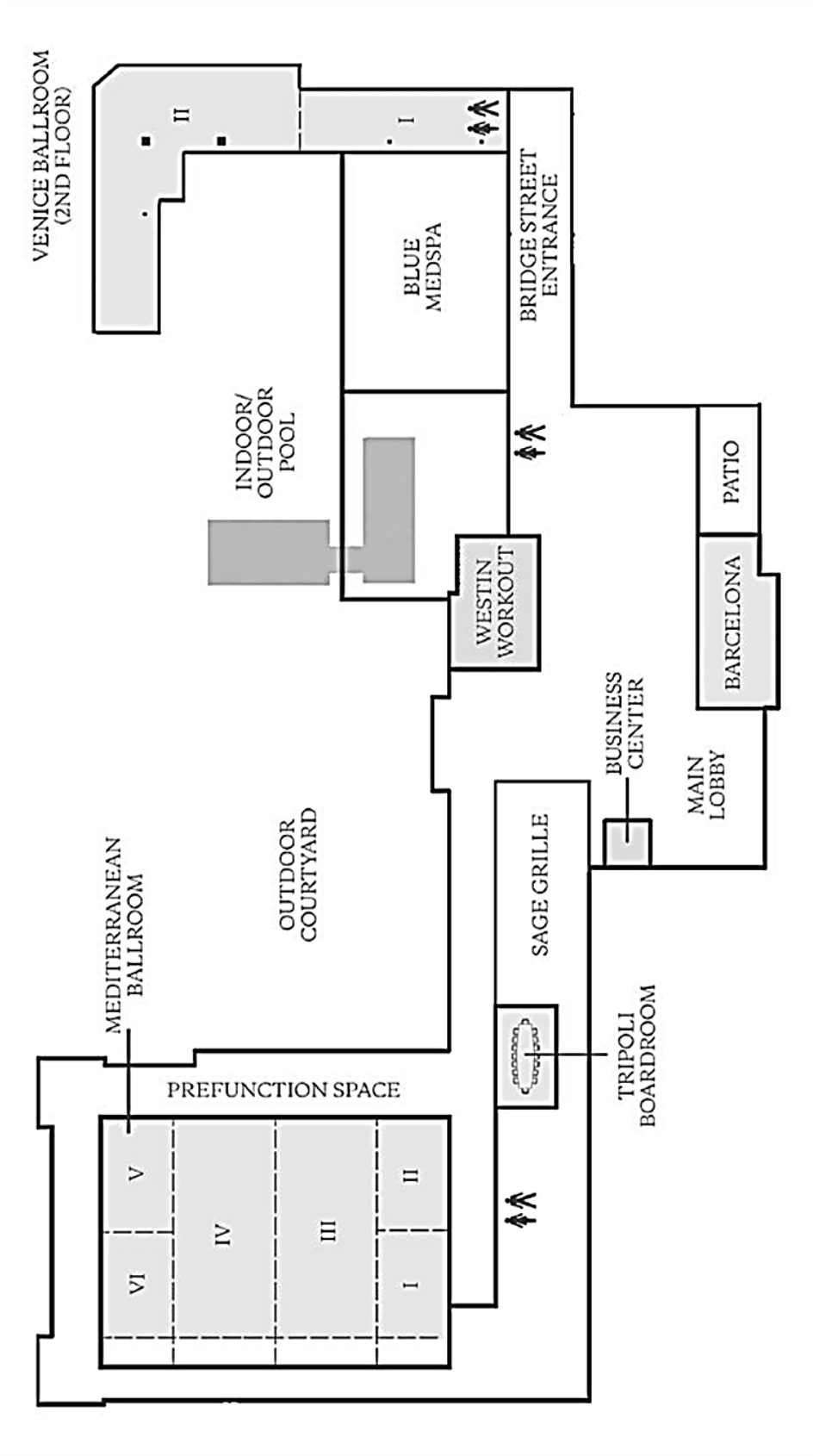
Please refer to The Westin Huntsville's website for information on Directions and Parking. Both Bridge Street Towne Centre and The Westin Huntsville offer complimentary parking throughout the property.



The Westin Huntsville  
6800 Governors West, NW,  
Huntsville, AL, 35806

“The Westin Huntsville blends sophistication, elegance and classic southern hospitality with the unique shopping, dining and entertainment of Bridge Street Town Centre. Located within Huntsville's Cummings Research Park and less than two miles from the U.S. Space and Rocket Center and the Redstone Arsenal. Conveniently located 15 minutes from the Huntsville Airport, The Westin Huntsville is more than an accommodation, it is a destination.”

The Westin Huntsville Map



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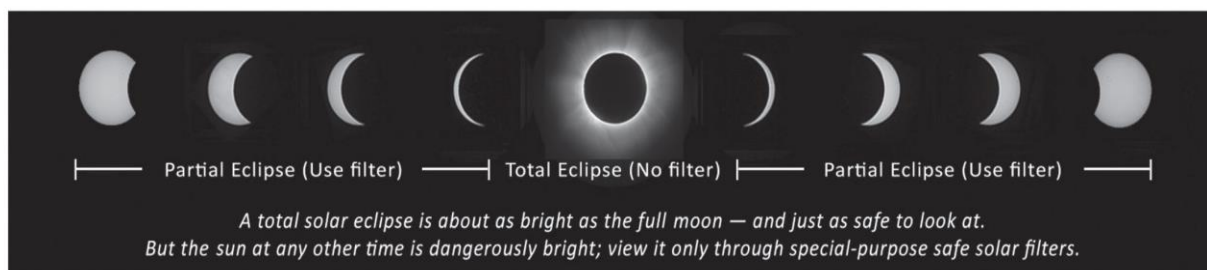
## Solar Eclipse Information

### Great American Eclipse - August 21, 2017

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A solar eclipse occurs when the moon blocks any part of the sun. On Monday, August 21, 2017, a solar eclipse will be visible (weather permitting) across all of North America. The whole continent will experience a partial eclipse lasting 2 to 3 hours. Halfway through the event, anyone within a roughly 70-mile-wide path from Oregon to South Carolina (<https://go.nasa.gov/2pC0lhe>) will experience a brief total eclipse, when the moon completely blocks the sun's bright face for up to 2 minutes 40 seconds, turning day into night and making visible the otherwise hidden solar corona — the sun's outer atmosphere — one of nature's most awesome sights. Bright stars and planets will become visible as well.



Looking directly at the sun is unsafe except during the brief total phase of a solar eclipse (“totality”), when the moon entirely blocks the sun’s bright face, which will happen only within the narrow path of totality.

The only safe way to look directly at the uneclipsed or partially eclipsed sun is through special-purpose solar filters, such as “eclipse glasses” or hand-held solar viewers. Homemade filters or ordinary sunglasses, even very dark ones, are not safe for looking at the sun. To date four manufacturers have certified that their eclipse glasses and handheld solar viewers meet the ISO 12312-2 international standard for such products: Rainbow Symphony, American Paper Optics, Thousand Oaks Optical, and TSE 17.

A solar eclipse is one of nature’s grandest spectacles. By following these simple rules, you can safely enjoy the view and be rewarded with memories to last a lifetime. For More Information: <https://eclipse2017.nasa.gov>

This document does not constitute medical advice. Readers with questions should contact a qualified eye-care professional.



## **Thermal Analysis Results Processor (TARP) and Capture Output and Verify Results (COVeR) Hands-on Training Course**

*Hume Peabody (Thermal Modeling Solutions)*

*8:00 AM – 12:00 PM*

*Room: Mediterranean I*

TARP and COVeR allow post processing of thermal model output files beyond the capabilities offered by other commercial tools. TARP allows a user to create a variety of objects (e.g. DataSets, Groups, Parameters, Tables, Plots, Backloads, Equivalent Sinks, etc.) which are then used to produce a Microsoft Excel® output file. A specialized, macro embedded workbook allows for heat flows to be computed and displayed at both a nodal and group level. COVeR is a separate tool which displays heat flows and model connectivity in a block diagram format. COVeR shows the user what is actually in the model and not just what they think is in the model; this can be used to find missing or unintended couplings as well as to define if a design has sufficient conductivity or isolation.

## **Introduction to Thermal Synthesizer System (TSS) and v15.01 Hands-On Training Course**

*Joe Lepore, Joe Clay (Spacedesign)*

*8:00 AM – 12:00 PM*

*Room: Mediterranean II*

This hands-on class will progress through a thermal analysis of a spacecraft using version v15.01. The student will go through each major step in the analysis process using a simple example. This is the basic framework needed to create, analyze, and obtain temperatures using TSS. The spacecraft model will begin as a CAD file, which is moved into TSS by using the Transfer application. As each TSS application is used, user interface and TSS features are demonstrated by the instructor and utilized by the student. Calculations of radks, heating rates, conduction/capacitance network, and temperatures are performed. The latest TSS capabilities demonstrated in this class include the return of the Executive application for Windows and SindaWin application. Everyone interested in learning how to perform satellite thermal analysis should attend this class.

## **Multi-Layer Insulation (MLI) Demo**

*Aleksandra Bogunovic (Aerothreads, Inc.)*

*9:00 AM – 10:00 AM*

*Room: Mediterranean V*

MLI blanket design and fabrication short course

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**Monday, August 21, 2017**  
**Break for Lunch/Eclipse - 12:00 PM – 2:00 PM**

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Enjoy lunch at The Westin Huntsville or Bridge Street Town Centre. The schedule has an additional hour for the lunch break for attendees to view the solar eclipse.

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## Monday, August 21, 2107

### Afternoon Sessions

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#### **COVeR: Capture Output and Verify Results**

*Hume Peabody (Thermal Modeling Solutions)*

*2:00 PM – 5:00 PM*

*Room: Mediterranean I*

TARP and COVeR allow post processing of thermal model output files beyond the capabilities offered by other commercial tools. TARP allows a user to create a variety of objects (e.g. DataSets, Groups, Parameters, Tables, Plots, Backloads, Equivalent Sinks, etc.) which are then used to produce a Microsoft Excel® output file. A specialized, macro embedded workbook allows for heat flows to be computed and displayed at both a nodal and group level. COVeR is a separate tool which displays heat flows and model connectivity in a block diagram format. COVeR shows the user what is actually in the model and not just what they think is in the model; this can be used to find missing or unintended couplings as well as to define if a design has sufficient conductivity or isolation.

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#### **STAMP Demo**

*Hans Guijt (Terma)*

*3:00 PM – 4:00 PM*

*Room: Mediterranean V*

STAMP is a software package for conducting thermal tests. It acquires data, presents it in various forms, and controls power supplies. It is geared towards large-scale testing, with thousands of sensors, dozens of acquisition devices, and hundreds of

power supplies. It supports fast scan rates and long test durations. During the demo we will prepare and conduct a small (simulated) test, demonstrating the capabilities of STAMP and answering any questions that may come up. STAMP has been used to test spacecraft in ESAs LSS facility since 2000.

### **Solving Conjugate Heat Transfer Problems with OpenFOAM 4.1**

*Franco Cascella (Université de Sherbrooke, Polytechnique Montréal)*

*2:00 PM – 4:00 PM*

*Room: Venice I*

Open-source software for computational fluid dynamic (CFD), such as OpenFoam, are gaining great interest among the scientific community. Effectively, this success is based not only on the possibility of using this software for free, but also on the opportunity for the user to modify and improve it. Nevertheless, the lack of a graphical user interface and the (apparently) limited documentation make it difficult for new users to learn this software. So, setting a CFD problem in OpenFoam may be challenging. In order to overcome these obstacles, during this presentation the following topics will be covered. Firstly, OpenFoam will be introduced by analyzing the installation directory; this is mandatory because the users must be able to locate the codes of the equation models. In this context, an example is provided by showing the code of the heat equation. Thereafter, it will be illustrated the procedure to solve a conjugate heat transfer problem with OpenFoam. The heat transfer problem involves the solution of a system of several differential equations, i.e., the Navier-Stokes equations for the fluid region and the heat equation for the solid one. A demo will be showcased and the following tasks will be accomplished: the generation of the geometry, the computation of the meshes, the solution of the governing equations and finally the post-processing. In this way, the attendants will get enough information to run their own cases with OpenFoam.

### **Veritrek Demo**

*Derek Hengeveld (Loadpath)*

*4:00 PM – 5:00 PM*

*Room: Venice I*

Built to enhance the capabilities of Thermal Desktop®, Veritrek produces thousands of simulation results in seconds by leveraging the power of reduced-order models (ROMs). Once an ROM has been constructed, you can quickly investigate variations in your Thermal Desktop model and in its environments using Veritrek's Exploration Tool. This tool provides advanced capabilities such as 2-D and 3-D plotting, sensitivity studies, screening analysis, and optimization studies. The Exploration Tool is built around a simple and intuitive interface that enables non-experts access to your thermal analysis. Veritrek benefits include reduced modeling costs, more optimized designs, improved analysis schedules, and a more collaborative environment. For more information please check out [www.veritrek.com](http://www.veritrek.com).



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## Monday, August 21, 2107

### Evening Activities

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#### **TFAWS Welcome Reception, 5:30 PM - 7:00 PM**



Bar Louie  
365 The Bridge St.  
Huntsville, AL 35806

We'd like to welcome all attendees and guests to attend the TFAWS Welcome Reception on Monday evening from 5:30pm to 7:00pm at Bar Louie. Let's keep the conversation flowing with our thermal and fluids analysis peers as well as MSFC Management. Bar Louie is located at Bridge Street Town Centre, just steps away from the Westin hotel as well as a myriad of dining and entertainment venues. This cool neighborhood restaurant specializes in oversized sandwiches and American traditional cuisine.

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**Tuesday, August 22, 2017**  
**Morning Sessions**

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**Passive Thermal Paper Session I**

*8:00 AM – 12:00 PM*

*Room: Mediterranean V*

*Session Chairs: Ryan Edwards (GRC), David Piryk (KSC), Daniel Forgette (JPL)*

- 8:00 AM      Improved Wedgelocks for Electronics Cooling**  
TFAWS2017-PT-01  
James E. Schmidt, Jens Weyant, William G. Anderson, Kevin Thorson
- 8:30 AM      Lessons Learned from SAGE III on ISS Thermal Vacuum Testing**  
TFAWS2017-PT-08  
Kaitlin Liles, Ruth Amundsen, Warren Davis
- 9:00 AM      Correlation of the SAGE III on ISS Thermal Models to Test and Flight Data**  
TFAWS2017-PT-02  
Ruth Amundsen, Warren Davis, Kaitlin Liles
- 9:30 AM      Thermochromic Variable Emittance Radiation Coatings for Spacecraft Thermal Management**  
TFAWS2017-PT-03  
Sydney Taylor, Liping Wang
- 10:00 AM     Thermal and Fluid Analysis of the Bigelow Expandable Activity Module (BEAM)**  
TFAWS2017-PT-04  
R. Scott Miskovich, Howard Matt, Grant Williams, Uy Duong, Lisa Thomas
- 10:30 AM     Thermal and Fluid Analysis and Design of the Nanoracks *Airlock*® MODULE**  
TFAWS2017-PT-05  
D. Shindich, R. S. Miskovich, H. Matt, B. Howe, M. Rowley
- 11:00 AM     Origami Tessellations as Variable Radiative Heat Transfer Devices**  
TFAWS2017-PT-06  
Rydge B. Mulford, Matthew R. Jones, Brian D. Iverson
- 11:30 AM     Cryogenic Multi-Layered Insulation Studies and Experiments**  
TFAWS2017-PT-07  
Justin Elchert

## **Introduction to RadCAD®**

*Douglas Bell (CRTech)*

*8:00 AM-12:00 PM*

*Room: Mediterranean I*

This session will provide an introduction to the capabilities of RadCAD through the creation of simple radiation models. RadCAD performs surface-to-surface radiation exchange calculations and environmental heating calculations. No previous experience with Thermal Desktop is expected. Experienced users are welcome but are requested to allow new users to have priority at the workstations.

## **Advanced Thermal Synthesizer System (TSS) including v15.01B and CAD Transfer Hands-On Training Course**

*Joe Lepore, Joe Clay (Spacedesign)*

*8:00 AM-12:00 PM*

*Room: Mediterranean II*

This hands-on class will demonstrate more TSS features and modeling techniques. Topics will include: Radiation analysis of CAD surfaces using STEP and IGES Translators, SindaWin application and using LDDATA to automatically record local minimum and maximum temperatures, Geometry model validation, building models with Symbols, distributed processing, managing Boolean surfaces and chains, adjusting conductor values, using the Mesh and FEM applications, and SATSTRAN. Topics of specific interest to users and v15 enhancements will be discussed. Example topics include the rich feature set in TSS such as programming in the command language, utilizing TSS as a prototyping tool, eliminating costly 3rd party applications to move data from a CAD package to a thermal software system, and utilizing TSS as a simple CAD package.

The Transfer application is used to view CAD models and transfer them into TSS geometry format. Transfer has a 'CAD viewer' built-in, allowing you to view any CAD model saved in IGES, STEP, or OBJ format. This viewer shows a meshed representation of the model which can then be transferred to TSS Geometry format in a single step. Using advanced 2-D and 3-D Boolean capabilities (computational geometry), complex CAD entities are converted into thermal surfaces using fewer surfaces for radiation analysis. Transfer methods available include direct conversion to files compatible with specific TSS versions, plus a 2-D mesh approximation using surfaces or boundary representation. This class will present a detailed walk-through of the Transfer process, including discussion of B-splines, sequence numbers, composite closed loops, and troubleshooting.

## **CAD-Embedded CFD (FloEFD) for earlier design analysis & applying 1D-3D CFD to fluid systems design**

*Chris Watson (Mentor, A Siemens Business)*

*9:00 AM - 10:00 AM*

*Room: Med VI*

An introduction to the capabilities of FloEFD, the fully CAD-Embedded fluid dynamics software, to allow frontloading of analysis earlier into the design process. FloEFD for Siemens NX, Solid Edge, PTC Creo, and CATIA V5 is designed to eliminate significant typical CFD process time overheads and provide a simulation tool suited for design engineer to analysis expert. The presentation will describe how to how to perform 3D CFD analysis within the familiar CAD environment, and the underlying technology that enables: quick handling and preparation of CAD geometry; fast robust automated meshing on CAD geometry using SmartCells™; guided simulation set up; and visualizing/analyzing results quickly for design decision making. Extensive parametric CFD studies for CAD geometry refinement or assessing multiple operational scenarios will be explained and a short live demonstration of several examples will show the typical user experience in the CAD Embedded interface. The presentation will conclude with discussion of the challenges involved in improving accuracy early on for simulating internal flow fluid systems. This section will introduce a method using 3D CFD results generated rapidly in FloEFD and a native characterization linkage to FloMASTER, the thermo-fluid 1D CFD tool, to better model specific components (such as cold plates) in an avionics liquid cooling system example model.

## **ThermoAnalytics TAItherm Tutorial and Software Demo**

*Craig Makens (ThermoAnalytics)*

*10:00 AM - 12:00 PM*

*Room: Med VI*

ThermoAnalytics will provide an overview and demonstration of our TAItherm thermal simulation software. The topics covered will include our advanced Human Thermal Model, methods for modeling Cabin Environmental Control Systems, and co-simulation with GT-SUITE for integrating 1D networks with a 3D transient model. The TAItherm Battery Thermal-Electrical model will be presented for performing transient analysis of electrical systems with battery cells and battery packs. Finally, a short overview of CoTherm, our new CAE coupling software which provide a powerful framework for building and monitoring complex co-simulation scenarios.

## **Space Launch System (SLS) Thermal Panel Session**

### **SBU/ITAR Session**

#### **Identification will be checked at the door**

*SLS Engineering (NASA and Prime Contractors)*

*8:00 AM-12:00 PM*

*Room: Venice I*

This technical interchange meeting will cover past, current and future SLS technical issues and proposed mitigating strategies in the disciplines of aerothermodynamics, thermal analysis and thermal protection systems. The panel members are experts in these disciplines and this panel will provide the current “thermal” state of the heavy-lift launch vehicle. The panel members will give a short overview of some of the challenges and then have open discussion with the audience to answer any questions.

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**Tuesday, August 22, 2017**

**Lunchtime Speaker**

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#### **Status of the Space Launch System Program**

*12:00 PM-1:00 PM*

*Room: Mediterranean III/IV*

*Speaker: Garry Lyles (MSFC), SLS Program Chief Engineer*

Lunch tickets may be purchased at the TFAWS registration desk.

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**Tuesday, August 22, 2017**  
**Afternoon Sessions**

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**Interdisciplinary Session Paper Session I**

*1:00 PM-5:00 PM*

*Room: Mediterranean V*

*Session Chairs: Chris Kostyk (AFRC), Tim Risch (AFRC)*

- |                |   |
|----------------|---|
| <b>1:00 PM</b> | <b>A System Level Mass and Energy Calculation for an In-Situ Resource Utilization (ISRU) CO<sub>2</sub> Capture and Collection Temperature Swing Adsorption Pump</b><br>TFAWS2017-IN-01<br>Hash Hasseeb |
| <b>1:30 PM</b> | <b>Unlock the Power of Your ROM</b><br>TFAWS2017-IN-04<br>Derek Hengeveld   |
| <b>2:00 PM</b> | <b>Correlation and Reduction of Space Thermal Mathematical Models</b><br>TFAWS2017-IN-03<br>Ignacio Torralbo  |
| <b>2:30 PM</b> | <b>BREAK (30 Minutes)</b>   |
| <b>3:00 PM</b> | <b>Modeling a Packed Bed Reactor Utilizing the Sabatier Process</b><br>TFAWS2017-IN-02<br>Malay Shah  |
| <b>3:30 PM</b> | <b>Small Satellite Solar Thermal Propulsion System Design: Initial Thermal Analysis</b><br>TFAWS2017-IN-06<br>Mookesh Dhanasar  |
| <b>4:00 PM</b> | <b>Thermal Analysis of an Active Heat Exchanger System for Energy Extraction from Oceanic Crust</b><br>TFAWS2017-IN-05<br>Arundhuti Banerjee  |

## **Siemens PLM Simcenter 3D Thermal and Flow**

*Carl Poplawsky (Maya Simulation Technologies)*

*1:00 PM-3:00 PM*

*Room Mediterranean I*

This 2-hour hands-on training session will take you through access and use of 3D assembly CAD geometry, geometry preparation (idealization), and preparation of a coupled thermal/flow simulation model, followed by solution and post-processing. At that point, you will address significant design changes and see how those changes flow down through the entire simulation process with minimal analysis re-work. You will leave this session with a better understanding of the advantages of the CAD-based approach to thermal/flow simulation.

## **Veritrek Hands-on Training Course**

*Derek Hengeveld (Loadpath)*

*3:00 PM-5:00 PM*

*Room Mediterranean I*

Built to enhance the capabilities of Thermal Desktop®, Veritrek produces thousands of simulation results in seconds by leveraging the power of reduced-order models (ROMs). Once an ROM has been constructed, you can quickly investigate variations in your Thermal Desktop model and in its environments using Veritrek's Exploration Tool. This tool provides advanced capabilities such as 2-D and 3-D plotting, sensitivity studies, screening analysis, and optimization studies. The Exploration Tool is built around a simple and intuitive interface that enables non-experts access to your thermal analysis. Veritrek benefits include reduced modeling costs, more optimized designs, improved analysis schedules, and a more collaborative environment. For more information please check out [www.veritrek.com](http://www.veritrek.com).

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*Joe Lepore, Joe Clay (Spacedesign)*

*1:00 PM-5:00 PM*

*Room: Mediterranean II*

This hands-on class will demonstrate more TSS features and modeling techniques. Topics will include: Radiation analysis of CAD surfaces using STEP and IGES Translators, SindaWin application and using LDDATA to automatically record local minimum and maximum temperatures, Geometry model validation, building models with Symbols, distributed processing, managing Boolean surfaces and chains, adjusting conductor values, using the Mesh and FEM applications, and SATSTRAN. Topics of specific interest to users and v15 enhancements will be discussed. Example topics include the rich feature set in TSS such as programming in the command language, utilizing TSS as a prototyping tool, eliminating

costly 3rd party applications to move data from a CAD package to a thermal software system, and utilizing TSS as a simple CAD package.

The Transfer application is used to view CAD models and transfer them into TSS geometry format. Transfer has a 'CAD viewer' built-in, allowing you to view any CAD model saved in IGES, STEP, or OBJ format. This viewer shows a meshed representation of the model which can then be transferred to TSS Geometry format in a single step. Using advanced 2-D and 3-D Boolean capabilities (computational geometry), complex CAD entities are converted into thermal surfaces using fewer surfaces for radiation analysis. Transfer methods available include direct conversion to files compatible with specific TSS versions, plus a 2-D mesh approximation using surfaces or boundary representation. This class will present a detailed walk-through of the Transfer process, including discussion of B-splines, sequence numbers, composite closed loops, and troubleshooting.

### **GT-SUITE Multi-Physics Overview**

*Jon Zenker, Jon Harrison (Gamma Technologies)*

*1:00 PM-2:00 PM*

*Room: Mediterranean VI*

Do you simulate complex systems requiring simulating multiple physical domains including fluids, thermal, electrical, mechanics and controls? Are you looking for a simulation tool that runs faster than 3D CFD, but powerful enough to provide predictive answers to highly transient problems? Would you like to provide better boundary conditions to CFD or FE thermal tools, or even co-simulate with these tools? If so, come learn about how GT-SUITE can be used for solving multi-physics related problems of complex systems including cryogenic propulsion and two-phase flow systems in this one hour software demonstration.

About Gamma Technologies: GT-SUITE is a unique transformational all-in-one CAE tool. On one level, it is recognized to be a worldwide leader in high-level system modeling (0D/1D). But that is just the start: uniquely in the industry GT-SUITE is also a detailed 3D modeling tool, with built-in structural and thermal 3D FEA (with in-situ meshers), 3-D multi-body dynamics with flexible bodies and 3D CFD. These are complemented by CAD modeling and automatic model generation from CAD.

What makes GT-SUITE especially powerful is that high-fidelity 3D component models are seamlessly integrated into 1D/0D system-level models, which supply them with accurate transient multi-physics boundary conditions and assure two-way interactions between all of the sub-systems.



## **Component and System Level Modeling of a Two-Phase Cryogenic Propulsion System for Aerospace Applications**

*Curtis Collie (Roush)*

*2:00 PM-3:00 PM*

*Room: Mediterranean VI*

Roush has employed component and systems level modeling tools to aid in the design and development of the key components found in the ULA (United Launch Alliance) IVF (Integrated Vehicle Fluids) System. The IVF system is a single system designed to replace three independent upper stage launch vehicle subsystems; helium pressurization system, the reaction control system and the electrical power storage subsystem.

## **Tecplot 360**

*Scott Imlay, Alan Klug (Tecplot)*

*3:00 PM-4:00 PM*

*Room: Venice I*

Tecplot will demonstrate advancements with Tecplot 360, including PyTecplot, our Python API, reading of Loci/CHEM data and the SZL file format for large datasets.

## **MSFC Center Tour**

*1:00 PM-5:00 PM*

Meet the bus at the front entrance of the Westin. You must have a ticket to attend the tour. Please wear comfortable, closed-toe shoes and bring your NASA PIV badge and/or your driver's license.

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## Tuesday, August 22, 2017

### Evening Activities

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#### **TFAWS Delegates Meeting (Invite Only)**

5:30 PM-7:00 PM

Room: Venice I

#### **Pints and Pixels, 6:00 PM - 9:00 PM**



Pints and Pixels  
115 Clinton Ave E  
Huntsville, AL 35801

All attendees and guests are invited to join the TFAWS committee at one of Huntsville's most unique nightlife locations: Pints and Pixels, located in downtown Huntsville (It is located inside the U.G. White building, take the elevator up to the 3rd floor.) The arcade showcases 35+ vintage video arcade games from the 80's and 90's along with 12+ pinball machines! Anaheim Chili's downtown location is right here inside Pints & Pixels, so attendees can try a variety of chili, burgers, sandwiches, and more. Come for the food or the games, you won't be disappointed!

**Monaco Theatre, 6:00 PM - 9:00 PM**



Monaco Theatre  
365 The Bridge St  
Huntsville, AL 35806

If you wish to do something more low key, the Monaco theatre is steps away from The Westin Hotel. On Tuesdays, Monaco offers \$5 tickets for all movies, including new releases! Enjoy an innovative upscale fourteen-screen movie entertainment experience with reclining seating. The Scene restaurant and lounge is located inside the theatre which features a Sushi bar and a large outside patio.

## Active Thermal Paper Session II

8:00 AM - 12:00 PM

**8:00 AM**      **An Innovative Methodology for Error Analysis of Thermo-Fluid Systems**  
TFAWS2017-AT-13  
David Dodoo-Amoo, Julio Mendez, Mookesh Dhanasar, Frederick Ferguson

**8:30 AM Two-Pendulum Model of Propellant Slosh in Europa Clipper PMD Tank**  
TFAWS2017-AT-14  
Wanyi Ng, David Benson

9:00 AM **Variable Geometry Radiator Sizing and Turndown Analysis for a Single Loop  
Spacecraft ATCS**  
TFAWS2017-AT-15  
Lisa Erickson

**9:30 AM**      **Acoustic Actuation for the Enhancement of Pool Boiling and Vapor Condensation**  
TFAWS2017-AT-16  
Thomas R. Boziuk, Marc K. Smith, Ari Gleze

**10:00 AM** **BREAK (15 Minutes)**

**10:15 AM      Non-toxic, High-performance Ultra-Low Temperature Fluids for Use in a Single-Loop Thermal Control System**  
TFAWS2017-AT-17  
J. Michael Cutbirth, Andrew Wagner, Ted Amundsen

**10:45 AM**      **Liquefaction Study of Gaseous Oxygen Inside Mars Ascent Vehicle Propellant Tank**  
TFAWS2017-AT-21  
Xiao-Yen Wang

**11:15 AM**      **High-Density Microchannel Cold Plate for Electronics Cooling**  
TFAWS2017-AT-19  
Sergey Semenov

## **Introduction to C&R Thermal Desktop® and FloCAD®**

*Douglas Bell (CRTech)*

*8:00 AM-12:00 PM*

*Room: Mediterranean I*

This session will provide an introduction to the capabilities of Thermal Desktop and FloCAD through the creation of simple models that include radiation and fluid flow. Thermal Desktop is a pre- and postprocessor for SINDA; FloCAD adds fluid model development based on thermal model geometry and flow path centerlines. No previous experience with Thermal Desktop is expected. Experienced users are welcome but are requested to allow new users to have priority at the workstations.

## **GT-SUITE Hands-On Training Course**

*Jon Zenker, Jon Harrison, (Gamma Technologies)*

*8:00 AM-12:00 PM*

*Room: Mediterranean II*

This hands-on class will demonstrate the multi-physics capabilities in GT-SUITE simulation software through building a handful of examples starting with 3D CAD geometry to produce a fluid thermal model of a cryogenic system, and account for effects such as water hammer due to fluid structure interaction of a transient valve event, as well modeling various cryogenic system components including turbomachinery and heat exchangers. Discussion on two-phase and reacting flows will also be considered. Finally, the user will be shown how to explore the design space easily through optimization and DOE, as well as post-process results with the built-in post processor.

About Gamma Technologies: GT-SUITE is a unique transformational all-in-one CAE tool. On one level, it is recognized to be a worldwide leader in high-level system modeling (0D/1D). But that is just the start: uniquely in the industry GT-SUITE is also a detailed 3D modeling tool, with built-in structural and thermal 3D FEA (with in-situ meshers), 3-D multi-body dynamics with flexible bodies and 3D CFD. These are complemented by CAD modeling and automatic model generation from CAD.

What makes GT-SUITE especially powerful is that high-fidelity 3D component models are seamlessly integrated into 1D/0D system-level models, which supply them with accurate transient multi-physics boundary conditions and assure two-way interactions between all of the sub-systems.

### **TSS Demo**

*Joe Clay (Spacedesign)*

*10:00 AM-11:00 AM*

*Room: Mediterranean V*

The latest version of TSS will be showcased with a demonstration of enhancements. The new TSS v16.01 features Augmented Conduction that uses Computational Geometry to produce conduction/capacitance networks for Spacedesign SINDA/FLUINT and Polarized Thermal Radiation Exchange using the index of refraction and extinction coefficient for radiation properties that vary based on ray progression. Additional enhancements like 32-character submodel names and multi-threaded graphics will also be discussed.

### **MSFC Infrared Thermography Team Demo**

*Darrell Gaddy (MSFC)*

*11:00 AM-12:00 PM*

*Room: Mediterranean V*

The MSFC Infrared Thermography team specializes in calibrated high temperature infrared thermography of propulsion element testing. The infrared thermography TFAWS demo will introduce the fundamentals of infrared thermography temperature measurements, techniques to capture wide temperature spans with high dynamic range infrared hardware and software, and show examples of propulsion testing.

### **Passive Thermal TDT (Invite Only)**

*8:00 AM - 12:00 PM*

*Room: Venice I*

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## **Wednesday, August 23, 2017**

### **Lunchtime Speaker**

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### **Advanced In-Space Propulsion Technologies for Exploring the Solar System and Beyond**

*12:00 PM-1:00 PM*

*Room: Mediterranean III/IV*

*Speaker: Les Johnson (MSFC)*

Lunch tickets may be purchased at the TFAWS registration desk.

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**Wednesday, August 23, 2017**  
**Afternoon Sessions**

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**Interdisciplinary Paper Session II**

*1:00 PM-4:00 PM*

*Room: Mediterranean VI*

- |                |  |
|----------------|--|
| <b>1:00 PM</b> | <b>Thermal Conductance Measurement and Flexibility Enhancement of Flexible Thermal Links</b><br>TFAWS2017-IN-09<br>Matt Felt                               |
| <b>1:30 PM</b> | <b>Interdependence of Length, Diameter and Strain States on the Thermal Transport Property of Nanostructures</b><br>TFAWS2017-IN-10<br>Vinu Unnikrishnan   |
| <b>2:00 PM</b> | <b>Effect of Solar Specularity and Ray-tracing Modeling in NX Thermal Solver on Thermal Analysis of SWOT Mission</b><br>TFAWS2017-IN-11<br>Lina Li Maricic |
| <b>2:30 PM</b> | <b>Co-Simulation Modelling of a Medium Sized Thermal Vacuum Facility for Test Feasibility Studies</b><br>TFAWS2017-IN-12<br>Matthew Vaughan                |
| <b>3:00 PM</b> | <b>Interactive LUROVA™ Thermal Model for the STEM Simulation Game</b><br>TFAWS2017-IN-13<br>Ron Creel  |

**CAD Embedded CFD hands-on workshop (Using FloEFD)**

*Ivan Andronov (Mentor, A Siemens Business)*

*1:00 PM-4:00 PM*

*Room: Mediterranean 1*

This hands-on workshop introduces performing fluid dynamics simulation directly the CAD Environment using FloEFD, fully CAD Embedded CFD Software and will include analysis of 3 examples including an internal flow component and an electronics cooling enclosure. FloEFD is designed to reduce typical CFD analysis time overheads and suit user levels from design engineer to expert. An introduction to the enabling technology will be followed by step by step guidance on model preparation, user interface, simulation set up, meshing and solution, to accessing results and running parametric studies. CAD-Embedded CFD possible with FloEFD for Siemens NX, Solid Edge, PTC Creo, CATIA V5 and

a stand-alone version feature fast robust automated meshing, quicker time to analysis using CAD geometry directly within the CAD interface, guided simulation set up and straight forward results post-processing. The rapid parametric studies capability for refining geometry, comparing designs or assessing a wide variety of operational conditions will also be demonstrated.

### **Winplot**

Kathryn Henkel (MSFC)

*1:00 PM-3:00 PM*

*Room: Mediterranean II*

Winplot is a multi-purpose highly intuitive and flexible plotting tool. It is used to plot test and analytical model results. It was developed for and has been historically used for rocket engine propulsion development and analysis. It can be used for propulsion hot fire real-time and post-test and post-flight evaluation. It has been used to support multiple NASA and industry rocket development and launch programs.

### **Fundamentals of Ablative Thermal Protection Materials**

Robin Beck (ARC-TSS), Darrell Davis (MSFC)

*1:00 PM-4:00 PM*

*Room: Mediterranean V*

This is a short course that covers the fundamentals of ablative thermal protection systems. It covers the definition of ablation, description of ablative materials, how they work, how to analyze them and how to model them.

### **Active Thermal TDT (NASA Civil Servant Only)**

*1:00 PM-4:00 PM*

*Room: Venice I*

### **Poster Session**

*4:00 PM – 5:00 PM*

*Room: Mediterranean III/IV*

Interesting technical work is featured on each poster, and the author will be available to discuss their poster.



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## Wednesday, August 23, 2017

### Evening Activities

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#### **TFAWS Dinner Banquet (must have a ticket)**

*United States Space and Rocket Center, Davidson Center*

*5:00 PM-9:00 PM*

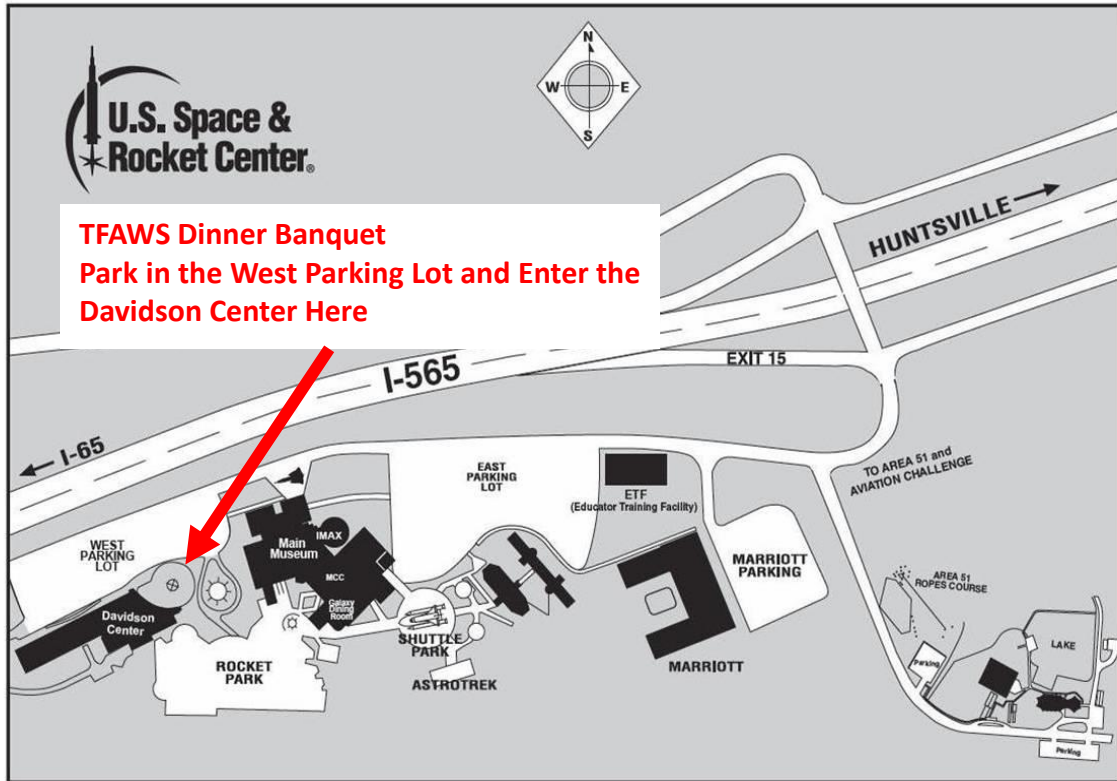


U.S. Space & Rocket Center, Davidson Center/Saturn V Hall  
1 Tranquility Base  
Huntsville, AL 35805

At the TFAWS banquet, you will be dining under an authentic Saturn V Apollo moon rocket, a National Historic Landmark at the U.S. Space and Rocket Center. The Saturn V Hall is surrounded by artifacts from the Space Program, and before the dinner begins, you will be able to explore the museum and its unique space exploration artifacts and exhibits. The doors for banquet ticket holders will open at 5 p.m., giving you a full 90 minutes to explore before dinner begins at 6:30 p.m.

To honor the historical rocket developer, Dr. Wernher von Braun, the banquet will be serving a German Fare with a vegetarian option (available upon request). The buffet dinner will be serving Schnitzel, Bratwurst, & Oven Roasted Chicken as the main items, with the vegetarian option being an Eggplant & Portabella Mushroom Schnitzel with Lemon Caper sauce. Sides include Sauerkraut, German Potato Salad, Green Beans, and Pretzel Rolls. A variety of German desserts will be presented on your dining tables, and Iced Tea and Water will be available.

# USSRC SITE MAP 1



**TFAWS Dinner Banquet**  
**Park in the West Parking Lot and Enter the**  
**Davidson Center Here**

U.S. Space & Rocket Center Map

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**Thursday, August 24, 2017**  
**Morning Sessions**

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**ITAR Paper Session**

*8:00 AM-10:00 AM*

*Room: Venice I*

*Session Chairs: Chris Morris (MSFC), Jacob Roth (KSC)*

- |                 |  |
|-----------------|--|
| <b>8:00 AM</b>  | <b>Porous Media Fluid Thermal Modeling for Heated Carbon Cloth Phenolic Composite Materials</b><br>TFAWS2017-AE-01<br>Louie Clayton                                    |
| <b>8:30 AM</b>  | <b>Space Launch System Green Run Base Thermal Protection System Testing at the MSFC Thermal Vacuum Chamber</b><br>TFAWS2017-AE-02<br>Manish Mehta                      |
| <b>9:00 AM</b>  | <b>The Transient Thermal Analysis Software Toolset: TTAS</b><br>TFAWS2017-AE-03<br>William Coirier   |
| <b>9:30 AM</b>  | <b>Loci-CHEM CFD Code Validation for Aerodynamic Heating Modeling of a High Fidelity ARES 1X Model</b><br>TFAWS2017-AE-04<br>Caroline P. Badger, Francisco Canabal III |
| <b>10:00 AM</b> | <b>Thermal Modeling for the SLS SPIE Structural Test Article (STA)</b><br>TFAWS2017-IN-14<br>Chris Evans   |
| <b>10:30 AM</b> | <b>RRM3 Source Dewar Burst Disk Modeling Using Thermal Desktop</b><br>TFAWS2017-AE-11<br>Dan Hauser  |
| <b>11:00 AM</b> | <b>RRM3 Propellant Transfer Performance Modeling Using Thermal Desktop</b><br>TFAWS2017-AE-12<br>Dan Hauser  |

## **COMSOL Multiphysics for Thermal and Fluid Analysis**

8:00 AM-12:00 PM

Angela Straccia (COMSOL)

Room: Mediterranean I

Learn how COMSOL Multiphysics can be leveraged to solve problems with conductive, convective and radiative heat transfer. COMSOL's computational fluid dynamics (CFD) capabilities allow both active and passive cooling systems to be modeled. Using COMSOL's integrated multiphysics simulation environment, complex problems with thermal stresses, phase changes, electromagnetic heating, chemical reactions, and other multiphysics phenomena can be rigorously analyzed.

## **Siemens PLM Simcenter 3D Space Systems Thermal**

Carl Poplawsky (Maya Simulation Technologies)

8:00 AM-10:00 AM

Room: Mediterranean II

This 2-hour hands-on training session will take you through access and use of spacecraft 3D assembly CAD geometry, geometry preparation (idealization), and preparation of an orbital thermal simulation model, followed by solution and post-processing. At that point, you will address significant design changes and see how those changes flow down through the entire simulation process with minimal analysis re-work. You will leave this session with a better understanding of the advantages of the CAD-based approach to orbital thermal simulation.

## **Siemens PLM FEMAP Advanced Thermal**

Carl Poplawsky (Maya Simulation Technologies)

10:00 AM-12:00 PM

Room: Mediterranean II

Femap Thermal/Flow is an effective CAE tool for both existing and new Femap users. This 2-hour hands-on training session will take you through access and use of 3D assembly CAD geometry and preparation of a coupled thermal/flow simulation model, followed by solution and post-processing. As a bonus, the instructor will also be showing the new Femap Thermal/Flow user interface to be released this fall with Femap 11.4.1. This major revision to Femap Thermal/Flow provides a consistent user experience across the Femap product suite and uncovers several important solver features not previously available to Femap users.

## **Cryogenic Fluid Management - CFM 101**

*Noah Rhys (Yetispace, Inc.)*

*8:00 AM – 10:00 AM*

*Room: Mediterranean V*

- What is a cryogen?
- What is CFM supposed to do?
- Why does CFM Matter
- Why is CFM difficult
- What are CFM Operations?
- Heat leak, insulation, mixing, stirring, venting, cooling, thermodynamic vent system, propellant transfer between tanks.
- Some typical boiloff numbers
- What is the state of the art?

## **Numerical Modeling of Cryogenic Fluid Management**

*Dr. Alok Majumdar (MSFC)*

*10:00 AM – 12:00 PM*

*Room: Mediterranean V*

This short course describes the basics of finite volume procedure in a fluid network and several applications of Cryogenic Fluid Management (CFM) using NASA's Generalized Fluid System Simulation Program (GFSSP). The applications include chilldown of cryogenic transfer line, no vent chill and fill, boil-

## **Introduction to On Orbit Thermal Environments**

*Steve Rickman (JSC-C104)*

*8:00 AM-12:00 PM*

*Room: Mediterranean VI*

Spacecraft on-orbit thermal control analyses are driven by environmental heating conditions. This math-based course provides a detailed introduction to the on-orbit thermal environment. Students will gain an understanding of the factors used to derive solar flux, albedo, and planetary infrared heating and how they are applied in real analyses. Expressions for environmental heating parameters will be derived. The beta angle is explored in detail including its derivation and its effect on the on-orbit thermal environment. The course concludes with illustrative examples designed to enhance the students' insights into on-orbit environmental heating.

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**Thursday, August 24, 2017**  
**Lunchtime Speaker**

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**Liquid Propulsion Systems Additive Manufacturing**

*12:00 PM-1:00 PM*

*Room: Mediterranean III/IV*

*Speaker: Graham Nelson (MSFC)*

Lunch tickets may be purchased at the TFAWS registration desk.

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**Thursday, August 24, 2017**  
**Afternoon Sessions**

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**Active Thermal Paper Session III**

*1:00 PM-5:00 PM*

*Room: Venice I*

*Session Chairs: Mark Cavanaugh (JSC), Eric Grob (GSFC), Monica Guzik (GRC)*

- 1:00 PM      Temporary Thermocouple Attachment for Thermal/Vacuum Testing at Non-Extreme Temperatures – Test Results**  
TFAWS2017-AT-20  
Sarah E. Wright, Eugene K Ungar
- 1:30 PM      Development of NASA’s Sample Cartridge Assembly: Summary of GEDS Design, Development Testing, and Thermal Analyses**  
TFAWS2017-AT-22  
Brian O’Conner, Deborah Hernandez, Linda Hornsby, Maria Brown, Kathryn Horton-Mullins
- 2:00 PM      Thermal System Design for Lunar/Martian Surface Regenerative Fuel Cell System**  
TFAWS2017-AT-23  
Ryan Gilligan
- 2:30 PM      Working Fluid Trade Study for a Two-Phase Mechanically Pumped Loop Thermal Control System**  
TFAWS2017-AT-25  
Stephanie Cappucci, Ben Furst, Eric Sunada, Pradeep Bhandari, Gajanana Birur, Brian Carroll

**Introduction to CRTech TD Direct®**

*Douglas Bell (CRTech)*

*1:00 PM-5:00 PM*

*Room: Mediterranean I*

This session will provide an introduction to the capabilities of CRTech TD Direct. TD Direct is powerful software that fills the gap between design geometry and C&R Thermal Desktop. TD Direct is an add-in to ANSYS® SpaceClaim®, a CAD tool that focuses on preparing geometry for analysis, just as Thermal Desktop is an add-in to AutoCAD. With TD Direct, the user is able to solve many of the problems that have challenged thermal engineers for years. The starting point is the full design geometry in any format. The final product is the completed analysis in Thermal Desktop. The step in between is TD Direct, where the user can easily simplify, heal, create, and alter the geometry while working with an exceedingly capable mesher.

## **Generalized Fluid System Simulation Program (GFSSP) Hands-on Training Course**

*Andre Leclaire, (MSFC)*

*1:00 PM-5:00 PM*

*Room: Mediterranean II*

GFSSP is a general-purpose computer program for analyzing steady-state and time-dependent flow rates, pressures, temperatures, and concentrations in a complex flow network. The program is capable of modeling phase change, compressibility, mixture thermodynamics, conjugate heat transfer, and fluid transient (waterhammer). GFSSP was been developed at MSFC for flow analysis of rocket engine turbopumps and propulsion systems. The class will show how the user can quickly develop a system-level thermo-fluid model, discuss the capabilities of the software, and present model examples. Students will build two models as a group activity, and have the opportunity to work one or more hands-on tutorials.

## **Future of NASA Aerosciences**

*By Mark D'Agostino (MSFC), Dr. Dave Schuster (LARC)*

*1:00 PM-3:00 PM*

*Room: Mediterranean V*

Mr. D'Agostino will present an overview of the strategic direction of NASA Aerosciences over the next several decades. Physics-Based Integrated System Simulation is the ultimate goal enabled by a combination of the five main Aerosciences sub-disciplines. The desired future state of Aerosciences will provide accurate, efficient flight simulation to support the design and qualification process while providing guidance to engineers.

## **Launch Vehicle Base Flows**

*Dr. Manish Mehta (MSFC)*

*3:00 PM-5:00 PM*

*Room: Mediterranean V*

This course will discuss the gas dynamics for multi-rocket engine launch vehicle base flows during lift-off to main-engine cut-off (MECO) and the technical challenges with predictions of such complex flows. The seminar will also present NASA heritage and innovative methods to accurately estimate base heating and pressure environments for launch vehicles including the Space Launch System, which is currently being built.

## **Introduction to Life Support Systems**

*By Jay Perry (MSFC), Dr. Morgan Abney (MSFC), Dr. Jim Knox (MSFC)*

*1:00 PM-5:00 PM*

*Room: Mediterranean VI*

This course provides an introduction to the design and development of life support systems to sustain humankind in the harsh environment of space. The life support technologies necessary to provide a respirable atmosphere and clean drinking water are



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**Thursday, August 24, 2017**  
**Evening Activities**

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## An aerial photograph of the University of Texas at Dallas campus. The image is overlaid with numerous circular icons, each containing a logo or symbol, connected by lines to specific buildings or areas on campus. The icons include the Lone Star logo, the UT Dallas logo, and various departmental or organizational logos. The campus is surrounded by trees and greenery, with roads and parking lots visible. The text "CAMPUS 805" is visible in the bottom right corner.

All attendees and guests are welcome to join the TFAWS committee at Campus 805. This Middle School closed in 2009 and was purchased, updated and redesigned as an entertainment center with breweries and restaurants. Straight to Ale is one of the local breweries located in Campus 805 and where we will meet for a friendly Cornhole competition between NASA centers and attendees. Straight To Ale has 20 plus taps of craft beer and offers food from Ale's Kitchen which serves gourmet burgers, wings and American style cuisine. Campus 805 is a popular location so feel free to visit the other craft breweries, restaurants, and bars all within walking distance!

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**Friday, August 25, 2017**  
**Morning Sessions**

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**Aerothermal Paper Session**

*8:00 AM-12:00 PM*

*Room: Mediterranean V*

*Session Chairs: Chris Morris (MSFC), Jacob Roth (KSC)*

- |                 |   |
|-----------------|---|
| <b>8:00 AM</b>  | <b>High-Order Shock-Fitting Solvers and Numerical Simulations of Hypersonic Non-Equilibrium Flows</b><br>TFAWS2017-AE-05<br>Xiaowen S. Wang, Ph.D.  |
| <b>8:30 AM</b>  | <b>Optical Diagnostic Imaging of Multi-Rocket Plume-Induced Base Flow Environments</b><br>TFAWS2017-AE-06<br>Manish Mehta, Ph.D.  |
| <b>9:00 AM</b>  | <b>Use of Venturi Tube for the observation of the variation of Wind thrust in Drone Technology</b><br>TFAWS2017-AE-07<br>Abu Saleh  |
| <b>9:30 AM</b>  | <b>Plume Induced Aerodynamic and Heating Models for the Low Density Supersonic Decelerator Test Vehicle</b><br>TFAWS2017-AE-08<br>Brandon Mobley  |
| <b>10:00 AM</b> | <b>Evaluating the Performance an Improved Finite Volume Method for Solving the Fluid Dynamic Equations</b><br>TFAWS2017-AE-09<br>Frederick Ferguson   |
| <b>10:30 AM</b> | <b>Physics Based Validation of an Improved Numerical Technique for Solving Thermal Fluid Related Problems</b><br>TFAWS2017-AE-10<br>Julio Mendez, David Doodoo-Amoo, Mookesh Dhanasar, Frederick Ferguson |

## **Winplot Session 2**

*Kathy Henkel (MSFC)*

*9:00 AM-11:00 AM*

*Room: Mediterranean I*

Winplot is a multi-purpose highly intuitive and flexible plotting tool. It is used to plot test and analytical model results. It was developed for and has been historically used for rocket engine propulsion development and analysis. It can be used for propulsion hot fire real-time and post-test and post-flight evaluation. It has been used to support multiple NASA and industry rocket development and launch programs.

## **New and Advanced Features in Thermal Desktop, Demo**

*Douglas Bell (CRTech)*

*9:00 AM-11:00 AM*

*Room: Mediterranean VI*

This session will provide an overview of new and advanced features within the Thermal Desktop suite and provide demonstration on the use of some of those features. This session is recommended to anyone who wishes to see more advanced capabilities of the Thermal Desktop suite than can be addressed in the introductory session. Since the session is not hands-on, prior experience with Thermal Desktop is not required. Thermal Desktop is a design environment for generating thermal models with additional modules for performing radiation and heating environment calculations (RadCAD) and generating fluid flow circuits (FloCAD). Thermal Desktop is a graphical user interface for SINDA/FLUINT.

## **MSFC Center Tour**

*8:00 AM-12:00 PM*

Meet the bus at the front entrance of the Westin. You must have a ticket to attend the tour. Please wear comfortable, closed-toe shoes and bring your NASA PIV badge and/or your driver's license.

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**Adjourn TFAWS 2017**

**12:00 PM**

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Thank you for being part of TFAWS 2017! We hope you have enjoyed your time in Huntsville, Alabama. TFAWS 2018 will be hosted by Johnson Space Center (JSC). Details will be available on the TFAWS website in the coming months.

### **Numerical Investigation of Heat Transfer from a Plane Surface Due to Annular Swirling Turbulent Jet Impingement**

TFAWS2017-AT-02

*Farhana Afroz, Muhammad A.R. Sharif*

*Aerospace Engineering and Mechanics Department,  
The University of Alabama Tuscaloosa, AL*

This paper presents numerical study of heat transfer characteristics of an annular turbulent swirling jet impingement on a plane heated surface. Annular jet configuration causes instabilities and fluctuations in the flow and depending on the combinations of different parameters, the annular jet impingement may have positive or negative effects on the heat transfer rate over impingement surface. On the other hand, swirl introduces vorticity and fluid mixing in impinging jet, which is desirable in some applications. Axisymmetric two-dimensional flow domain with and without swirling flow is considered in this study. The RNG k-epsilon turbulence model with enhanced wall treatment is used in the computation. Earlier studies on turbulent swirling impinging jet flow configuration demonstrated superior performance of this turbulence model. The numerical computations are conducted using the ANSYS Fluent code. The computational process is validated against other published data on similar flow configuration for non-swirling and swirling annular impinging jets. The flow and geometric parameters are the jet exit Reynolds number,  $Re$ , the swirl strength  $Sw$ , the jet exit to target surface distance,  $H$ , and the blockage ratio of the annular jet,  $B$ . Various combinations of these parameters are considered and the thermal-hydraulic field in the domain is computed. The effects of these parameters on the Nusselt number distribution on the impingement surface is investigated. This study will help to understand the complex flow behavior of the swirling annular jet impingement and help to find the optimal combinations of the different parameters to obtain the desired heat transfer distribution on impingement surface as well as the desired level of fluid mixing.

### **Optimization of the Giant Magellan Telescope M1 Off-Axis Mirror Cell Thermal Control System**

TFAWS2017-AT-03

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The Giant Magellan Telescope Organization (GMTO) is responsible for the development of the Giant Magellan Telescope (GMT). The GMT is a ground-based telescope designed for operation over the wavelength range 320 nm to 25  $\mu\text{m}$ . In order for the telescope to operate correctly and efficiently, it is imperative to minimize the thermal time constant so that the mirrors equilibrate uniformly and as rapidly as possible to ambient conditions. Any deformations or local convective cells from the top surface of the mirror can distort the optics. Each mirror segment is made of borosilicate glass which has low thermal conductivity and a relatively high coefficient of thermal

expansion. Additionally, the mirror has numerous air-filled cores so that conduction alone is insufficient to create an efficient thermal feedback system. This paper describes ATA Engineering, Inc.'s computational fluid dynamics (CFD) and thermal analyses of the GMT M1 off-axis mirror cell. The project was motivated by the need for an analytical model that would demonstrate a telescope design that meets the telescope's thermal requirements by introducing and optimizing a forced cooling system. The analysis was completed in a multistep process. First, breakout CFD simulations modeling the air within a single core for varying nozzle designs were analyzed. From the CFD results, heat transfer coefficient (HTC) correlations based on geometry and mass flow rates were developed for various regions within the core. From these correlations as well as a flow network model of the M1 off-axis mirror cell system, a MATLAB script was created that allows the user to define certain nozzle design parameters, and it outputs the HTCs of a converged nozzle design such that thermal time constants ( $\tau$ ) for all cores—and, thus, the entire mirror—were as low and uniform as possible. A thermal model was then built using a previously created structural finite element model (FEM). Conduction, convection, and radiation heat transfer were incorporated into the model, with the correlated HTCs imported as inputs to the model. Finally, the optimized design and PDR baseline design were analyzed and compared. The optimized design reduces the thermal time constant by a factor of two (from 71 to 36 minutes) while also reducing the nonuniformity in thermal time constant by a factor of 5 (from  $\pm 15$  min to  $\pm 3$  min).

#### **Advanced Passive Thermal Experiment for Hybrid Heat Pipes and HiK™ Plates on board the International Space Station**

TFAWS2017-AT-04

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As NASA prepares to further expand human and robotic presence in space, it is well known that spacecraft architectures will be challenged with unprecedented thermal environments in deep space. In addition, there is a need to extend the duration of the missions in both cold and hot environments, including cis-lunar and planetary surface excursions. The heat rejection turn-down ratio of the increased thermal loads in the above-mentioned conditions is crucial for minimizing vehicle resources (e.g. power). Therefore, future exploration activities will have the need of thermal management systems that can provide higher reliability and performance, and power and mass reduction. In an effort to start addressing the current technical gaps in thermal management systems, novel new passive thermal technologies have been selected to be included as part of suite of experiments to be tested on the board of the International Space Station (ISS), tentatively in 2017.

## **LHP Wick Fabrication via Additive Manufacturing**

TFAWS2017-AT-06

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While loop heat pipes (LHPs) are capable of transporting heat across deployable radiators they are currently too expensive for many applications such as CubeSats and SmallSats. The largest cost comes from the fabrication of the primary wick which requires multiple machining steps as well as a knife-edge seal. In this work the feasibility of fabricating a loop heat pipe (LHP) primary wick using a direct metal laser sintering (DMLS) process was investigated. 3D printing a LHP wick can significantly reduce fabrication costs by eliminating machining steps and the risk of failure can be reduced by eliminating the knife-edge seal. The challenge with 3D printing of a LHP primary wick is achieving a small enough pore radius to supply sufficient capillary pumping power. A pore radius and permeability study was conducted using a range of DMLS methods and parameters to optimize for LHP primary wicks. A 3D printed primary wick was designed and fabricated with a fully dense outer shell for direct welding to the compensation chamber and vapor line. A complete LHP prototype was built and tested to demonstrate the performance of the 3D printed wick.

## **2-Phase Refrigeration Thermal Management for High Altitude Balloon Platforms**

TFAWS2017-AT-09

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A growing field in the planetary science community has been the use of large high altitude balloons to launch scientific payloads into the stratosphere for making observations uninhibited by Earth's atmosphere. Recent advances in balloon technology are allowing larger payloads and longer duration missions, than had previously been possible. With such advancement has come greater challenges for the flight systems included with the payloads. The Gondola for High Altitude Planetary Science (GHAPS) is an optical telescope being developed by NASA GRC, NASA MSFC, and NASA GSFC. At 1 meter in diameter, it will be the largest diffraction limited telescope to fly on a high altitude balloon when it launches from Ft. Sumner, NM in 2020. The program is planned for 5 total missions from various launch sites including Antarctica and New Zealand, with the potential to last up to 100 days at float. GHAPS is being designed as a facility to incorporate multiple scientific instruments affixed to its optical telescope assembly. The support of such instruments includes providing power and heat removal. With an allocation of over 500W of continuous power, the instruments will have a significant heat load requiring an active thermal management solution. Previous balloon payloads that are similar in concept to GHAPS have used circulating liquid loops to transport the instrument heat load to a space pointing radiator for rejection. However, due to the mass and power constraints on GHAPS, a new solution was required to reject the varying heat load at any orientation. A new system was designed that uses a single phase liquid loop to transport heat from the instrument to a heat exchanger where a 2-phase refrigeration cycle picks up the heat and increases the quality to be rejected by the radiator. The refrigeration system offers several distinct performance advantages over the circulating liquid loop. The primary advantage comes by using a radiator as the condensing portion of the refrigeration cycle. This allows for a higher radiator temperature and therefore a

smaller radiator total area. It also increases the ability to reject heat regardless of time of day or exposure to solar flux. Night time power consumption is decreased by eliminating the need for radiator heaters during eclipse or periods of low heat load, since the compressor can be cycled proportionally to the load. The system is currently under development at NASA GRC. It has been modeled and designed, with an engineering development unit (EDU) under construction for testing in a thermal vacuum chamber.

#### **Four Bed Molecular Sieve – Exploration (4BMS-X) Heater Design and Analysis**

TFAWS2017-AT-10

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A 4BMS-X (Four Bed Molecular Sieve – Exploration) design and heater optimization study for carbon dioxide sorbent beds in proposed exploration system architectures is presented. The primary objectives of the study are to reduce heater power within the CO<sub>2</sub> sorbent beds while reducing channeling effects relative to existing designs. Some of the notable changes from the ISS (International Space Station) CDRA (Carbon Dioxide Removal Assembly) to the proposed exploration system architecture include cylindrical beds, alternate sorbents and an improved heater core. Results from both 2D and 3D sorbent bed thermal models with integrated heaters are presented. The 2D sorbent bed models are used to optimize heater power and fin geometry while the 3D models address end effects in the beds for more realistic thermal gradient and heater power predictions.

#### **An Innovative Methodology for Error Analysis of Thermo-Fluid Systems**

TFAWS2017-AT-13

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One of the most important goals of this research effort is to improve the efficiencies of computational fluid dynamic (CFD) tools by focusing on the development of a numerical procedure with improved flow physics capturing capabilities. The intent is to create a numerical procedure that solves the Navier-Stokes (NS) Equations under a wide variety of initial and boundary conditions, efficiently and accurately. This new scheme, which was initially described in Ref. [1–8] and referred to as the Integro-Differential Scheme (IDS), has several favorable qualities. For instance, the scheme is developed based on a unique combination of the differential and integral forms of the Navier-Stokes Equations, hence the name, IDS. The focus of this paper, however, is on the qualitative evaluation of the IDS solution that were generated from a set of ‘commonly described’ complex fluid dynamic problems. Among the fluid dynamic problems chosen are (i) the ‘inviscid-viscous boundary layer’ interaction problem at the leading edge of a hypersonic flat plate, (ii) the ‘supersonic rearward facing step’ problem, and (iii) the interactions due to the ‘sonic jet injection into a supersonic cross-flow’. It is of interest to note, the IDS procedure does not rely on turbulence models, and as such, in analyzing the IDS results of the three selected fluid dynamic problems no such considerations are addressed. Notwithstanding the lack of turbulence models, overall the IDS results compares extremely well with the available experimental data.

## **Two-Pendulum Model of Propellant Slosh in Europa Clipper PMD Tank**

TFAWS2017-AT-14

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The objective of this fluids analysis is to model propellant slosh for the Europa Clipper mission using a two-pendulum model, such that GNC (Guidance, Navigation, and Control) can predict slosh behavior during the mission. Propellant slosh causes shifts in center of mass and exerts forces and torques on the spacecraft which, if not adequately controlled, can lead to mission failure. The two-pendulum model provides a computationally simple model that GNC can use to predict slosh for the Europa Clipper tank geometry, which is cylindrical with a domed top and bottom and includes a PMD (propellant management device). Due to the lack of experimental data in low gravity environments, CFD (computational fluid dynamics) simulation results were used as “real” slosh behavior for two propellants at three fill fractions. Key pendulum parameters were derived that allow the pendulum model’s center of mass, forces, and moments to closely match the CFD data. The parameter trends were examined as a function of tank fill fraction and compared with analytical approximate equations where available. The trends were monotonic as expected, and parameters resembled analytical predictions; any differences could be explained by the specific differences in the geometry of the tank. This paper summarizes the new method developed at GSFC (Goddard Space Flight Center) for deriving pendulum parameters for two-pendulum equivalent sloshing models and the results of this method. This analysis is at a completed stage and will be applied in the immediate future to the evolving tank geometry as Europa Clipper moves past its PDR (preliminary design review) phase.

## **Variable Geometry Radiator Sizing and Turndown Analysis for a Single Loop Spacecraft ATCS**

TFAWS2017-AT-15

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Recently, NASA has invested in the development of a variable geometry radiator that employs Shape Memory Alloys (SMAs) to passively adjust the radiator’s view to space. This technology is potentially useful for increasing the variable heat rejection capabilities of future manned spacecraft Active Thermal Control Systems (ATCSs) and for preventing the freezing of non-toxic working fluids required by single loop systems. Single loop architectures are viewed as an attractive means to reduce mass and complexity over traditional dual-loop solutions. Fluids generally considered safe enough to flow within crewed cabins (e.g. propylene glycol-water mixtures) have much higher freezing points and viscosities than those used in the external sides of dual loop ATCSs (e.g. Ammonia and HFE7000). Conceptually, the radiator consists of multiple panels that have a naturally closed cylindrical shape to reduce heat rejected to space in low vehicle heat load cases. SMAs integrated into each panel are tailored such that their temperature dependent phase change will result in the gradual opening of each panel as a function of temperature to a full-open semicircular shape. Short radiator panels are required to prevent temperature gradients along a panel’s length from driving SMAs to unevenly open the panel. Prototype flexible composite radiator panels are currently under development at Texas A&M



(3 inch length with 3 inch closed diameter). A thermal vacuum test conducted at JSC in summer 2016 demonstrated their ability to successfully actuate from SMA wires.

Previously, a joint study conducted by Jacobs, Texas A&M, and NASA showed the potential benefits of morphing radiator technology to manned spacecraft. The analysis relied on commonly used environmental sink temperatures and did not account for discrete opening and closing of multiple-radiator panels along a flow path. A higher fidelity thermal model was needed to evaluate the variable heat rejection capability of radiator designs currently in development. Traditional steady-state hand radiator sizing and heat rejection calculations employed for most body mounted radiators cannot easily be applied to this technology. The complex radiation exchange of the curved panels, which results in parasitic heating of the radiator to itself, is better calculated with a Monte Carlo method in a finite difference model. However, geometrically representing hundreds of small panels to model a spacecraft's entire radiator would be tedious, and conducting a sizing analysis in this manner would require much effort. This paper describes a method for steady-state modeling of a vehicle sized variable geometry radiator within Thermal Desktop/SINDA FLUINT. The Dynamic SINDA feature is leveraged to obtain solutions for an entire radiator from a geometric representation of a manageably sized radiator segment. A technique is also described for performing a radiator sizing analysis and determining the radiator's minimum allowable operational heat load in a single loop ATCS. This modeling approach, when applied to either a flat or curved panel, has been shown to agree with results produced from hand calculations which use known fin efficiencies and sink temperatures.

### **Acoustic Actuation for the Enhancement of Pool Boiling and Vapor Condensation**

TFAWS2017-AT-16

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Phase-change heat transfer processes that involve boiling and condensation are common in high-heat flux applications, such as cooling high-density electronics and industrial power cycles. The present work in this ongoing study of these processes demonstrates that 1.7 MHz acoustic actuation can be used to control of the rate of vapor formation on and transport from a heated surface (along with a substantial extension of the critical heat flux limit). Heat transfer is further improved using structured surfaces that form separate nucleation sites designed to limit the merger of vapor bubbles above the surface and to enable an efficient inflow of makeup liquid to the evaporation sites.

The boiling curves for a plain heated surface in the absence and presence of actuation show that the actuation effectively shifts the boiling curve to the right (i.e., increased superheat) and extends the CHF from 110 to 183 W/cm<sup>2</sup> (66%). Images of vapor formation on the surface show that at low heat flux (25 W/cm<sup>2</sup>) the actuation reduces the number of nucleation sites as evidenced by the lower concentration of vapor bubbles on the surface and that the surface superheat increases to compensate for this effect.

A heated surface with a grid of open microchannels having a width of 400  $\mu$ m is used in conjunction with acoustic actuation for further enhancement. With the microchannels and no

actuation the CHF is increased to 350 W/cm<sup>2</sup>, primarily because the microchannels restrict boiling to the bottom of the channels, with the plateaus preventing the spread of vapor that ultimately leads to CHF. In addition, rising vapor entrains fresh fluid to the boiling sites through the surrounding microchannels. The addition of 1.7 MHz acoustic actuation results in a further increase of CHF to 463 W/cm<sup>2</sup>. The acoustic actuation also decreases the superheat along the boiling curve, exactly opposite to the effect on superheat seen for a smooth surface. This effect is further investigated in this work using a smooth surface featuring surface-embedded thermocouples for direct measurement at a nucleation site. It is shown that at preferred nucleation sites, such as a defect or the bottom of a microchannel, the effect of acoustic actuation is modified from the effect on a plain surface.

For many applications, the subsequent condensation of rising vapor bubbles is limited by the heat transfer at the liquid-vapor interface and therefore may pose limitations on the scale of the condenser enclosure and limit the system's heat flux. Therefore, accelerated vapor condensation within the bulk liquid may offer significant efficiency gains. Acoustic actuation of the liquid-vapor interface is used to induce significant perturbations and even breakup of the interface and thereby increase the condensation rate and accelerate the reduction in volume of the vapor bubble. Depending on the acoustic wavelength, the applied perturbations can couple to the liquid-vapor interface either by scaling with the characteristic wavelength of unstable surface waves (sonic actuation) or by exploiting the mismatch between the acoustic impedance between the liquid and vapor phases to induce local interfacial deformations (ultrasonic actuation). It is shown that sonic [O(1 kHz)] actuation in the bulk liquid accelerates the vapor condensation rate by forming surface capillary waves at the liquid-vapor interface, while ultrasonic [O(1 MHz)] actuation leads to the ejection of a spout of subcooled liquid into the vapor volume resulting in the rapid collapse of vapor bubble. These enhancement techniques are demonstrated using water vapor bubbles that are formed by direct injection from a pressurized steam reservoir through nozzles of varying characteristic diameters, and are advected within an acoustic field of programmable intensity in a quiescent tank of subcooled water at atmospheric pressure (the effectiveness of the approach is also demonstrated at sub-atmospheric pressures). High-speed image processing is used to assess the effect of the actuation on the dynamics and temporal variation in the characteristic scale (and condensation rate) of the vapor bubbles, with an estimated increase in the time-averaged heat transfer coefficient of up to 425 percent.

## **Non-toxic, High-performance Ultra-Low Temperature Fluids for Use in a Single-Loop Thermal Control System**

TFAWS2017-AT-17

*Andrew Wagner, Ted Amundsen, J. Michael Cutbirth*

The current state-of-the-art thermal control system (TCS) consists of a two-loop, internal and external, architecture with a non-toxic fluid used inside the pressurized spacecraft and a low-freeze-point fluid for the external loop connected via an inter-loop heat exchanger adding substantial mass to the system. A single-loop TCS with variable heat rejection is sought for future missions that expand outside of low earth orbit. In its simplest form, this can be achieved using a heat transfer fluid (HTF) that has a very low freeze point with optimized thermal performance and is non-toxic, non-flammable, and non-corrosive. We used cheminformatic techniques to determine potential new HTFs with freeze points below -90°C and optimized thermal performance. Data from chemicals with known properties were used to generate predictive models of fluid properties. The properties of interest to this study are thermal conductivity, viscosity, heat capacity, density, boiling point, flash point, and melting point. The models were optimized to best predict larger and more complex molecules. The chemicals predicted to be the best performers were then further evaluated for internal loop safety concerns, i.e. toxicity and flammability. The potential HTFs were experimentally evaluated to validate the model predictions and compared to commercially available ultra-low temperature fluids. Finally, steps for improving the safety rating of the ultra-low temperature fluid have been explored. Model development, property testing, and experimental demonstration as part of a single-loop thermal control system will be presented.

## **Temporary Thermocouple Attachment for Thermal/Vacuum Testing at Non-Extreme Temperatures – Test Results**

TFAWS2017-AT-20

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Post-test examination and data analysis that followed a two week long vacuum test showed that numerous self-stick thermocouples became detached from the test article. The thermocouples were reattached with thermally conductive epoxy and the test was repeated to obtain the required data. Because the thermocouple detachment resulted in significant expense and rework, it was decided to investigate the temporary attachment methods used around NASA and to perform a test to assess their efficacy. The present work describes the testing that was performed in early and mid-2017. The test article and the temporary thermocouple attachment methods tested are described. During the first test, fully half of the thermocouples detached – although the detachment showed subtly in the data for some. The second test was performed to confirm the data from the first test and to investigate the effect of test article and thermocouple grounding. The results of the testing over temperatures ranging from -150 to 200°F are detailed and preliminary recommendations are made for temporary thermocouple attachment methods.

## **Liquefaction Study of Gaseous Oxygen Inside Mars Ascent Vehicle Propellant Tank**

TFAWS2017-AT-21

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The in-situ production of propellants for Mars missions will utilize carbon dioxide (CO<sub>2</sub>) in the Mars atmosphere to produce oxygen. The oxygen then needs to be cooled, liquefied, and stored to be available for Mars ascent propulsion, which could be up to 2 years after liquefaction starts. Recent investigations have demonstrated the feasibility of both achieving zero boiloff and controlling the pressure of oxygen within a tank using high-efficiency reverse turbo-Brayton-cycle cryocoolers. A representative configuration of tube-on-tank liquefaction using a cryocooler is shown in Fig. 1. The gas circulating in the cryocooler system is maintained slightly below liquid oxygen saturation temperature and is routed through a network of cooling tubes. The oxygen gas produced from the in-situ production process is introduced into the chilled tank. Two cases are considered in this work, one is that the warmer oxygen gas at 273 K fills into the tank, another case is the cooler oxygen gas at 100 K by assuming pre-chilling the gas oxygen before filling the tank. A series of analysis of this configuration has been performed to investigate the liquefaction rate inside the tank, the thermal gradient near the top of the tank where the oxygen gas feeding tubing is located. The analyses include 2D axisymmetric CFD analysis using ANSYS Fluent, 1D thermal analysis using Matlab, and 3D thermal analysis 2 using MSC Patran/Pthermal. These three models correlate and validate each other. The detailed analysis results of each model will be presented in the final paper.

## **Development of NASA's Sample Cartridge Assembly: Summary of GEDS Design, Development Testing, and Thermal Analyses**

TFAWS2017-AT-22

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NASA's Sample Cartridge Assembly (SCA) project is responsible for designing and validating a payload that contains a materials research sample in a sealed environment. The SCA will be heated in the European Space Agency's (ESA) Low Gradient Furnace (LGF) that is housed inside the Material Science Research Rack (MSRR) located on the International Space Station (ISS). The first Principle Investigator (PI) to utilize the SCA will focus on Gravitation Effects on Distortion in Sintering (GEDS) research. This paper will give a summary of the design and development test effort for the GEDS SCA and will discuss the role of thermal analysis in developing test profiles to meet the science and engineering requirements. Lessons learned will be reviewed and salient design features that may differ for each PI will be discussed.

## **Thermal System Design for Lunar/Martian Surface Regenerative Fuel Cell System**

TFAWS2017-AT-23

*Ryan Gilligan NASA GRC/LTF*

The AES Modular Power Systems (AMPS) Project is investigating different power systems for various lunar and Martian mission concepts. The AMPS Fuel Cell (FC) team created two system-level models to evaluate the performance of two regenerative fuel cell (RFC) systems employing different fuel cell chemistries. Proton Exchange Membrane (PEM) fuel cells contain a polymer electrolyte membrane that separates the hydrogen and oxygen cavities and conducts hydrogen cations (protons) across the cell. Solid Oxide fuel cells (SOFCs) operate at high temperatures, using a zirconia-based solid ceramic electrolyte to conduct oxygen anions across the cell. The purpose of the modeling effort is to down select one fuel cell chemistry for a more detailed design effort. Figures of merit include the system mass, volume, round trip efficiency, and electrolyzer charge power required. PEM FCs operate at around 60 °C versus SOFCs which operate at temperatures greater than 700 °C. Due to the drastically different operating temperatures of the two chemistries the thermal control systems (TCS) differ. The PEM TCS is less complex and is characterized by a single pump cooling loop that uses deionized water coolant and rejects heat generated by the system to the environment via a radiator. The SOX TCS has its own unique challenges including the requirement to reject high quality heat and to condense the steam produced in the reaction. This paper discusses the modeling of thermal control systems for an extraterrestrial RFC that utilizes either a PEM or SOX fuel cell.

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## Passive Thermal Paper Session Abstracts

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### **Improved Wedgelocks for Electronics Cooling**

TFAWS2017-PT-01

*James E. Schmidt, Jens Weyant, William G. Anderson, Kevin Thorson*

Developing higher capability spacecraft payloads requires advancements in digital signal processing. However, as capability increases, improvements in thermal management will be required to maintain electrical components within specified operating temperature ranges. Currently, electronics enclosures on spacecraft limit performance and reliability due to ineffective thermal management techniques. Therefore, improving the thermal management capabilities of the electronics enclosures aboard spacecraft is a key area of interest for improving payload capabilities. Advanced Cooling Technologies, Inc. (ACT), in collaboration with Lockheed Martin Advanced Technology Laboratories (LM-ATL), designed, developed, and demonstrated a prototype Isothermal Card Edge (ICE-Lok™) retainer to improve the heat rejection from slice form-factor cards to industry standard size chassis assemblies. The ICE-Lok™ expands in two directions to maximize the contact area between the card module and chassis to reduce the thermal interface resistance. Evaluations of the ICE-Lok™ retainer have demonstrated a 50% increase in thermal conductance compared to a COTS Wedgelock. Thus, the ICE-Lok™ has demonstrated increased capability to improve heat rejection from computing components, thereby enabling increases in spacecraft payload capability.

## **Correlation of the SAGE III on ISS Thermal Models to Test and Flight Data**

TFAWS2017-PT-02

*Ruth Amundsen, Warren Davis, Kaitlin Liles (NASA Langley Research Center)*

*Shawn McLeod, Analytical Mechanics Associates (AMA)*

*Kim Martin, Northrop Grumman Technical Services*

The Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument is the fifth in a series of instruments developed for monitoring aerosols and gaseous constituents in the stratosphere and troposphere. SAGE III was launched in February 2017 and mounted to the International Space Station (ISS) to begin its three-year mission. A detailed thermal model of the SAGE III payload, which consists of multiple subsystems, has been developed in Thermal Desktop (TD). Correlation of the thermal model is important since the payload will be expected to survive a three-year mission on ISS under varying thermal environments. Three major thermal vacuum (TVAC) tests were completed during the development of the SAGE III Instrument Payload (IP); two subsystem-level tests and a payload-level test. Additionally, a characterization TVAC test was performed in order to verify performance of a system of heater plates that was designed to allow the IP to achieve the required temperatures during payload-level testing; model correlation was performed for this test configuration as well as those including the SAGE III flight hardware. This document presents the methods that were used to correlate the SAGE III models to TVAC at the subsystem and IP level, including the approach for modeling the parts of the payload in the thermal chamber, generating pre-test predictions, and making adjustments to the model to align predictions with temperatures observed during testing. Correlation to the initial flight data taken during operation on ISS will be presented. Model correlation quality will be presented and discussed, and lessons learned during the correlation process will be shared.

## **Thermochromic Variable Emittance Radiation Coatings for Spacecraft Thermal Management**

TFAWS2017-PT-03

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Variable emittance radiators can provide variable heat rejection capabilities for missions with significant changes in thermal environment and spacecraft heat loads to prevent electronics and transport fluids from going below operable temperatures. One way to accomplish variable emittance is through surface coatings whose radiative properties change either with voltage input (electrochromics) or temperature (thermochromics). Vanadium dioxide (VO<sub>2</sub>) is a thermochromic insulator-to-metal phase transition material which typically undergoes a drastic change in optical properties at 341 K. This property shift can be taken advantage of to design variable emittance coatings for use in a variety of spacecraft thermal control applications. The thermochromic properties of the VO<sub>2</sub> allow the coating to adjust its radiative properties according to its surface temperature. When the system temperature is high, the coating has comparatively high mid-infrared emissivity to promote radiative cooling through heat rejection. Conversely, when the system temperature is low, the coating has low emissivity to prevent additional heat loss. By adjusting its emissivity based on temperature, a multilayer radiation coating which integrates VO<sub>2</sub> can adapt its radiative properties according to changes in spacecraft heat load or environment.

In this study, VO<sub>2</sub> thin films are fabricated using an electron beam evaporation and furnace oxidation technique. A comprehensive parametric investigation is undertaken to examine the effect of fabrication parameters such as oxygen flow rate, furnace time, vanadium starting film thickness, and temperature. The thin films are fabricated both on silicon and quartz substrates. The composition of the oxidized films is then determined using X-Ray Diffraction (XRD) and Rutherford Backscattering Spectrometry (RBS). The thickness and surface roughness of the film are determined using Atomic Force Microscopy (AFM). The temperature-dependent transmittance and reflectance of the fabricated thin films is measured using FTIR spectroscopy from the visible to mid-infrared wavelength regimes. The VO<sub>2</sub> thin film on quartz achieves a 32% transmittance change at 2.5  $\mu\text{m}$  wavelength, with a lowered transition range from 320 K to 340 K.

The optical properties of the fabricated VO<sub>2</sub> will be extracted from the temperature-dependent FTIR measurements for both the metallic and insulating phases. The experimental data for the insulating VO<sub>2</sub> will be fit to a Lorentz model and the experimental data for the metallic VO<sub>2</sub> will be fit to a Drude model. The transitioning VO<sub>2</sub> is modeled via the Bruggeman effective medium theory. The final sample fabricated will be a Fabry-Perot multilayer emitter which consists of a silicon spacer inserted between a VO<sub>2</sub> thin film and an opaque aluminum substrate. When the sample temperature is low, the coating is reflective due to the aluminum substrate properties. On the other hand, when the sample temperature is high, the VO<sub>2</sub> becomes metallic and forms the Fabry-Perot cavity. The corresponding Fabry-Perot resonance leads to an emission enhancement around 10  $\mu\text{m}$  wavelength. The temperature-dependent reflectance of this sample will be measured in the mid-infrared spectrum and will be compared to the theoretical performance of the structure.

### **Thermal and Fluid Analysis of the Bigelow Expandable Activity Module (BEAM)**

TFAWS2017-PT-04

*R. Scott Miskovich, Howard Matt, ATA Engineering, Inc.*

*Grant Williams, GWilliams Engineering*

*Uy Duong, Lisa Thomas, Bigelow Aerospace*

Expandable habitats show great promise as a cornerstone technology for future human habitation in space. Bigelow Aerospace, in partnership with NASA, designed and installed the world's first expandable, commercially-owned module on the International Space Station (ISS). The module, known as the Bigelow Expandable Activity Module, was initially intended as a two-year technology demonstrator to prove out the use of expandable soft good structures for space station habitation. BEAM has been operational on the ISS since May 2016 and its favorable performance to date has resulted in an extension of BEAM beyond the initial two-year design to allow for hosting of experiments and to provide valuable stowage for ISS equipment.

As a unique space structure that did not permit the use of onboard heaters, the thermal design and performance of BEAM was a critical feature in the development of BEAM. ATA and Bigelow Aerospace worked jointly to address this challenge by performing thermal and fluid analyses of BEAM on ISS and within the SpaceX Dragon trunk in order to verify thermal performance and ensure compliance with NASA requirements. Thermal models of BEAM were created using Thermal Desktop. CFD analyses of BEAM with ISS IMV were performed to verify proper air flow while on station and to establish accurate heat transfer coefficients to be used within the Thermal



Desktop model. Thermal analyses of BEAM were assessed in both packed and inflated configurations, and for various mission phases, resulting in several 100's of cases. This presentation will focus on model development, material test validation, ICD verification as well as a comparison of BEAM thermal design predictions and the internal BEAM temperatures measured in operation on ISS.

### **Thermal and Fluid Analysis and Design of the Nanoracks Airlock® MODULE**

TFAWS2017-PT-05

*D. Shindich, R. S. Miskovich, H. Matt, ATA Engineering, Inc.*

*B. Howe, M. Rowley, NanoRacks LLC*

In May 2016, NanoRacks and NASA signed a Space Act Agreement in order to install a private airlock module onboard the International Space Station (ISS) – the first in station history. The NanoRacks Airlock Module will provide an enhanced capability to deploy cubesat and small satellite systems from station and include a full range of additional services to meet customer needs from NASA and the growing commercial sector. The Airlock will be both a permanent commercial uncrewed module onboard ISS, and also a module capable of being removed from the space station and used on a future commercial platform. NanoRacks is currently in the detailed design phase of the Airlock, which is scheduled to launch in 2019.

The thermal design and performance of the Airlock is a critical feature of its development due to the environments associated with deployment operations. Given the myriad of thermal environments, pressurization conditions, and strict touch temperature limits for critical components, a passive thermal solution is being developed to minimize heater power consumption while meeting stringent ISS-specific requirements.

To help guide the thermal design and verify compliance to ISS requirements, ATA Engineering, Inc. and NanoRacks developed a system-level thermal model of the Airlock in Thermal Desktop. This model is being used to predict its thermal response during the various operational phases in order to yield a robust thermal control scheme. These phases include SpaceX Dragon free-flight, Space Station Remote Manipulator System (SSRMS) extraction from Dragon trunk, ISS Node 3 berthing, payload deployment and contingency operations. In addition to the thermal model, CFD analyses of Airlock with ISS IMV are being performed to verify proper air flow while on station and to establish accurate heat transfer coefficients to be used within the Thermal Desktop model. This paper provides an overview of the Airlock Module thermal design and describes the thermal analysis, trade studies, and development tests based on the Airlock's unique operational requirements and environmental conditions while minimizing heater power and conductive heat loss from internal surfaces.

## **Origami Tessellations as Variable Radiative Heat Transfer Devices**

TFAWS2017-PT-06

*Rydge B. Mulford, Matthew R. Jones, Brian D. Iverson*

Spacecraft radiators capable of dynamic control of heat loss to the environment would reduce the need for survival heating and enable more efficient use of power and weight budgets. Origami tessellations, or repeating fold patterns, are proposed as a technology that would allow for control of radiative heat loss. As a tessellation is actuated, the individual panels form cavities with increasing depth to width ratios. Radiative energy reflects multiple times within these cavities, increasing the number of absorption events that occur before the remaining energy exits the cavity. This behavior causes the opening of the cavity, when treated as a surface, to exhibit variable radiative surface properties, termed apparent emissivity and apparent absorptivity. Physical and numerical experiments are presented that demonstrate an increase in apparent emissivity and apparent absorptivity as accordion, modified-accordion, Miura-Ori or Barreto's Mars tessellations are collapsed. A model for the net radiative heat transfer between the environment and a collapsing tessellation is also presented that accounts for the changing projected surface area. Finally, initial concepts of an origami-inspired radiator are presented.

## **Lessons Learned from SAGE III on ISS Thermal Vacuum Testing**

TFAWS2017-PT-08

*Kaitlin Liles, Ruth Amundsen, Warren Davis*

*NASA Langley Research Center (LaRC)*

The Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument is the fifth in a series of instruments developed for monitoring aerosols and gaseous constituents in the stratosphere and troposphere. SAGE III was launched in February 2017 and mounted to the International Space Station (ISS) to begin its three-year mission. Three major thermal vacuum (TVAC) tests were completed during the development of the SAGE III Instrument Payload (IP); two subsystem-level tests and a payload-level test. Additionally, a characterization TVAC test was performed in order to verify performance of a system of heater plates that was designed to allow the IP to achieve the required temperatures during payload-level testing. This document presents an overview of the subsystem-level tests but focuses on the payload-level tests. A description of the test setup and approach will be provided, followed by lessons learned throughout the process of the design of the heater plate system, development of the payload-level test plan, definition of the test setup, and execution of the test. Lessons related to logistics and communication will be shared along with those which are more technical in nature.

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## ITAR Paper Session Abstracts

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### **Porous Media Fluid Thermal Modeling for Heated Carbon Cloth Phenolic Composite Materials**

TFAWS2017-AE-01

*J. L. Clayton*

*NASA MSFC, Huntsville, AL*

Carbon Cloth Phenolic (CCP) materials are commonly used as solid rocket motor (SRM) ablative liners for thermal protection of nozzle structural housings. Extensive test and analytical work has been performed by NASA with the objective of improved first principled understanding of the thermo-structural response of the material. Most failure modes associated with CCPs (pocketing, ply-lifting) are related to loads induced in the solid material due to buildup of internal pressures from thermal decomposition of the phenolic resin matrix material. The nature of heated material coupled thermo-structural response is complicated by many concurrent processes such as resin thermal kinetics, chemical/thermal kinetic dependent mechanical properties, multiphase in-depth pyrolysis product flow, and highly non-linear thermal and non-elastic structural response. This paper discusses the computational methodologies used in advanced thermal porous media codes developed at NASA MSFC. Results of model response for common heated CCP material tests such as free thermal expansion (FTE), restrained thermal growth (RTG), and structural analogs are examined. Direct coupling between the fluid and structural response are characterized to the extent that increased understanding of the relationship between the fluid phase behavior, pressures, and solid material response may be inferred with more accuracy than previously possible.

### **The Transient Thermal Analysis Software Toolset: TTAS**

TFAWS2017-AE-03

*William J. Coirier, James Stutts, Michael A. Robinson*

*Kratos Security and Defense*

In this presentation we summarize the development and testing of a transient aero-thermal analysis capability designed for the evaluation of high-speed vehicle Thermal Protection Systems (TPS). This Transient, Thermal Analysis Software (TTAS) toolset has been developed from a combination of new and existing open-source and government developed software tools. TTAS couples a very capable legacy thermal protection system model (the Aeroheating and Thermal Analysis Code-ATAC) with flow fields generated using the proven MSIC-TIGER (Missile and Space Intelligence Center - Topology Independent Gridding Euler Refinement) Computational Fluid Dynamics (CFD) code, and a new, distributed parallel, transient, three-dimensional, multi-material conductive and radiative heat transfer model that has been developed specifically for this effort. The TTAS suite allows the efficient and coupled transient, three-dimensional in-depth, trajectory-based thermal analysis of thermal protection systems on new high speed and hypersonic vehicles for Test and Evaluation purposes.

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## Aerothermal Paper Session Abstracts

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### **High-Order Shock-Fitting Solvers and Numerical Simulations of Hypersonic Non-Equilibrium Flows**

TFAWS2017-AE-05

*Xiaowen Wang, Ph.D.*

*Aerospace Engineering and Mechanics Department*

*The University of Alabama, Tuscaloosa, AL*

High-order numerical simulations of hypersonic/non-equilibrium flows have received considerable attention in the research community in the past two decades because of their potential in delivering high-order accuracy. In this presentation, I will first summarize the achievements in developing of high-order shock-fitting solvers for both perfect gas flows and high-enthalpy non-equilibrium flows. These solvers have been successfully applied to hypersonic flow simulations including boundary-layer stability and transition control, and direct numerical simulation of turbulent flow interacting with strong shocks. As an example, I will discuss the patent for a new control strategy of laminar hypersonic flow by using discrete surface roughness. Finally, I will go through future directions of high-order numerical simulations related to astronautic and aeronautic applications such as thermal protection system, low boom supersonic jet, and flow around high-speed vehicles and through their propulsion systems.

### **Use of Venturi Tube for the observation of the variation of Wind thrust in Drone Technology**

TFAWS2017-AE-07

*Md. Abu Saleh, Third year, BSc in Civil Engineering,*

*Rajshahi University of Engineering & Technology*

*Md. Roknuzzaman, Third year, BSc in Civil Engineering,*

*Rajshahi University of Engineering & Technology*

The wind thrust that a drone needs while taking off the ground, must be greater to its self-weight and the atmospheric pressure acting on it. Most often, drones are operated to its ultimate revolution per minute to make enough thrust to lift it above the ground. In rocket propulsion, venturi tube is used to make a huge thrust in order to complete a successful lift off. The actual purpose of this study is to observe the characteristics of wind thrust variation due to the adaptation of this venturi tube system in drones. The numerical values of wind thrust excluding the venturi tube and including the venturi tube are to be compared in this study. This concept is different as only the application of venturi tube is mainly used in rocket propulsion, jet engine especially in higher mechanical devices. But, drone was not assisted to this system before which can be said that it will save the electrical energy in a more efficient way without reducing the performance. The whole experiment is currently under testing and relevant data are being collected.

## **Plume Induced Aerodynamic and Heating Models for the Low Density Supersonic Decelerator Test Vehicle**

TFAWS2017-AE-08

*Brandon L. Mobley, NASA Marshall Space Flight Center, Huntsville, Alabama*

*Sheldon D. Smith, Plumetech, Huntsville, Alabama*

*John Van Norman, Analytical Mechanics Associates, Hampton, Virginia*

*Suman Muppidi, Analytical Mechanics Associates, Mountain View, California*

*Ian Clark, NASA Jet Propulsion Laboratory, Pasadena, California*

The methodology and development of plume induced aerodynamic and heating models for the Low Density Supersonic Decelerator (LDSD) test vehicle is presented. The LDSD test vehicle falls within a unique class of balloon-assisted launch vehicles whose specific purpose is to test supersonic deceleration technologies (suited for Mars payloads) within the Earth's upper stratosphere. To achieve freestream test conditions similar to that experienced during Mars entry, the vehicle is tethered to a helium balloon to ascend to an altitude of approximately 36.5 km (120 kft) where it is released and is accelerated along a ballistic trajectory. A single solid rocket kick motor burns for approximately 68 seconds throughout the powered phase, lofting the vehicle to approximately Mach 4.2 at 53 km (170 Kft). Vehicle attitude spin stabilization is initiated prior to ascent using two pairs of solid rocket motors. Post powered phase, an additional two pairs of solid rocket motors are fired to terminate the spin. Two Supersonic Flight Dynamics Tests (SFDT-1 and SFDT-2) occurred on June 28, 2014 and June 8, 2015, respectively. Pre-flight and post-flight plume induced aerodynamic and heating models were generated to predict the plume induced forces, moments and heat fluxes experienced during the spin-up, powered ascent, and spin-down phases. Comparisons of the predictions with post-flight reconstruction data are provided. Relatively good agreement was observed between the flight data and predictions from the highest fidelity models.

## **Evaluating the Performance an Improved Finite Volume Method for Solving the Fluid Dynamic Equations**

TFAWS2017-AE-09

*Frederick Ferguson, Julio Mendez, David Dodoo-Amoo Mookesh Dhanasar*

*(Corresponding Author: fferguso@ncat.edu)*

*Mechanical Engineering Department, NCAAT, Greensboro*

One of the most important goals of this research effort is to improve the efficiencies of computational fluid dynamic (CFD) tools by focusing on the development of a robust and accurate numerical framework capable of solving the Navier-Stokes Equations under a wide variety of initial and boundary conditions. The new scheme, which was initially described in Ref. 1 and referred to as the Integro-Differential Scheme (IDS), has several favorable qualities. For instance, the scheme is developed based on a unique combination of the differential and integral forms of the Navier-Stokes Equations (NSE). In this paper, the differential form of the NSE is used for explicit time marching and the integral form is used for spatial flux evaluations. As such, the scheme has the potential to accurately capture the complex physics of fluid flows. In addition, the Method of Consistent Averages (MCA) numerical procedure directly provides continuity of the numerical flux quantities rather than manipulating the primitive flowfield variables to ensure

continuity. Coupled temporal and spatial analyses of the mass, momentum, and energy fluxes are considered at two major locations; namely, at the center of the numerical control volume, and at each of the surface making up an elementary control volume. It is also of interest to note that the IDS procedure developed herein is based on two fundamental types of control volumes. This paper elaborates on the development of the IDS procedure and presents the results of its implementation on three established fundamental high Reynolds number fluid dynamic problems. The problems of interest to this study are the supersonic rearward facing step and the supersonic cavity flow problems. A careful analysis of the results generated from the use of the IDS procedure confirms its predictive capability and supports its potential to solve a variety of fluid dynamics problems.

### **Physics Based Validation of an Improved Numerical Technique for Solving Thermal Fluid Related Problems**

TFAWS2017-AE-10

*Julio Mendez, David Dodoo-Amoo, Mookesh Dhanasar Frederick Ferguson  
Mechanical Engineering Department, NCAT, Greensboro, NC*

Computational Fluid Dynamics (CFD) has played an important role in designing and evaluating different hypersonic devices, such as airfoils and scramjet/ramjet isolators among others. CFD provides useful information that along with traditional wind tunnel experiments enhances the understanding of different phenomena where analytical solutions are not available. Although important progress has been made in the last decades, there are no unique methods capable of solving a wide class of problems. Similarly, interpreting the approximate solution that comes as a collection of numbers is not a trivial task. It is mandatory to present the results in an organized fashion and extract relevant information directly and accurately. The most important goal of this research is to demonstrate the physics capture capabilities of a novel scheme called Integro-Differential Scheme (IDS) [1]. Previous works demonstrated that the scheme is accurate and robust under a wide variety of initial and boundary conditions. Nonetheless, the IDS is still in its developmental and testing stages. The contribution of this work is to prove its accuracy in terms of its ability to capture complex flow phenomena using Flow Feature Extraction Functions (FFEF). These functions use the primitive variables to identify and detect shock waves, zones with high unsteadiness and vortices. This approach supplements the traditional way of exploring datasets using contour plots of primitive variables. To date, the preliminary results show that IDS has the capabilities of accurately predicting the complex physics of fluid flows. Some FFEF can lead to false indications of important flow features but evidence shows that a combination of them is necessary to precisely pin-point them. The problems of interest in this study are the hypersonic shockwave boundary layer interaction (SWBLI) and the compressible internal flow, with applications to shock train problems.

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## Interdisciplinary Paper Session Abstracts

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### **A System Level Mass and Energy Calculation for a Temperature Swing Adsorption Pump used for In-Situ Resource Utilization (ISRU) on Mars**

TFAWS2017-IN-01

*Hashmatullah Hasseeb, Anthony Lannetti*

*NASA Glenn Research Center*

A major component of a Martian In-Situ Resource Utilization (ISRU) system is the CO<sub>2</sub> acquisition subsystem. This subsystem must be able to extract and separate CO<sub>2</sub> at ambient Martian pressures and then output the gas at high pressures for the chemical reactors to generate fuel and oxygen. The Temperature Swing Adsorption (TSA) Pump is a competitive design that can perform this task using heating and cooling cycles in an enclosed volume. The design of this system is explored and analyzed for an output pressure range of 50 kPa to 500 kPa and an adsorption temperature range of -50 °C to 40 °C while meeting notional requirements for two mission scenarios. Mass and energy consumption results are presented for 2-stage, 3-stage, and 4-stage systems using the following adsorbents: Grace 544 13X, BASF 13X, Grace 522 5A and VSA 10 LiX.

### **Modeling a Packed Bed Reactor Utilizing the Sabatier Process**

TFAWS2017-IN-02

*Malay G. Shah, Anne J. Meier, Paul E. Hintze*

*NASA, Kennedy Space Center*

A numerical model is being developed using Python which characterizes the conversion and temperature profiles of a packed bed reactor (PBR) that utilizes the Sabatier process; the reaction produces methane and water from carbon dioxide and hydrogen. While the specific kinetics of the Sabatier reaction on the Ru/Al<sub>2</sub>O<sub>3</sub> catalyst pellets are unknown, an empirical reaction rate equation<sup>1</sup> is used for the overall reaction. As this reaction is highly exothermic, proper thermal control is of the utmost importance to ensure maximum conversion and to avoid reactor runaway. It is therefore necessary to determine what wall temperature profile will ensure safe and efficient operation of the reactor. This wall temperature will be maintained by active thermal controls on the outer surface of the reactor.

Two cylindrical PBRs are currently being tested experimentally and will be used for validation of the Python model. They are similar in design except one of them is larger and incorporates a preheat loop by feeding the reactant gas through a pipe along the center of the catalyst bed. The further complexity of adding a preheat pipe to the model to mimic the larger reactor is yet to be implemented and validated; preliminary validation is done using the smaller PBR with no reactant preheating. When mapping experimental values of the wall temperature from the smaller PBR into the Python model, a good approximation of the total conversion and temperature profile has been achieved.

A separate CFD model incorporates more complex three-dimensional effects by including the solid catalyst pellets within the domain. The goal is to improve the Python model to the point where the results of other reactor geometry can be reasonably predicted relatively quickly when

compared to the much more computationally expensive CFD approach. Once a reactor size is narrowed down using the Python approach, CFD will be used to generate a more thorough prediction of the reactor's performance.

### **Correlation and Reduction of Space Thermal Mathematical Models**

TFAWS2017-IN-03

*Ignacio Torralbo, Javier Piqueras, Isabel Perez-Grande, Angel Sanz-Andres*

*IDR/UPM, Universidad Politécnica de Madrid*

Model-to-test correlation is a frequent problem in spacecraft-thermal control design. The idea is to determine the parameters of the thermal mathematical model (TMM) that makes a good fit between the TMM results and test data, in order to reduce the uncertainty of the mathematical model. Quite often, this task is performed manually, mainly because a good engineering knowledge and experience is needed to reach a successful compromise, but the use of a mathematical tool could help to facilitate the work. The correlation process can be stated as the minimization of the error of the model results with regard to the reference data.

The method presented is suitable to solve the TMM-to-test correlation problem as well as the reduction of the thermal mathematical model. It uses the Jacobian matrix formulation and Moore-Penrose pseudo-inverse. One of the advantages among other methods is that many loads cases can be easily included in the process.

The method have been applied in the Electronic Unit TMM, part of the PHI instrument of ESA Solar Orbiter mission, to be flown in 2019. The results are presented in the present work.

### **Unlock the Power of Your ROM**

TFAWS2017-IN-04

*Derek Hengeveld, PhD, PE*

*LoadPath*

Reduced order models (ROMs) are efficient surrogates to more computationally expensive high-fidelity computer models. Properly developed, ROMs provide near real-time simulations with accurate results and enable new analyses previously impractical with computationally-expensive high-fidelity simulation approaches. For example, ROMs can be used early in the design process to evaluate myriad design approaches and later to quickly verify a design envelope. The result is time/cost savings in addition to better optimized designs. Consequently, there is a need for the development of ROMs that can capture the effects of high-resolution computer experiments without incurring significant computational expense.

A method for creating and using ROMs for Thermal Desktop models was developed based on Latin Hypercube sampling and Gaussian-Process data fitting. Testing showed that 1,000s of thermal simulations could be completed in seconds. A robust algorithm for creating ROMs will be summarized and include details of sampling and data fitting schemes. Case studies, including a ROM developed for the NASA Crew Exploration Vehicle will be presented. It will be shown that the developed ROM did a good job replicating temperature, hydraulic power, and pressure responses for three different working fluids. Advantages/disadvantages of this approach compared to traditional thermal modeling will be discussed. Finally, an overview of Veritrek will



be provided. Veritrek was developed as a ROM exploration tool that enables advanced analysis including screening, factor sweeps, 3-D plotting, and optimization studies. Built for Thermal Desktop, this easy-to-use new software tool can provide more optimized designs, reduced costs, and improved schedules.

**Thermal Analysis of an Active Heat Exchanger System for Energy Extraction from Oceanic Crust**  
TFAWS2017-IN-05

*Arundhuti Banerjee<sup>1</sup>, Tanusree Chakraborty<sup>2</sup>*

*Indian Institute of Technology (IIT) Delhi*

In order to secure the future generations from energy crisis and disastrous climatic changes, it is highly beneficial to harness renewable energy resources like wind, ocean wave, geothermal energy and so on. A novel concept of incorporating a heat exchanger system in an offshore wind turbine structure has been proposed. This will run as a binary power plant system installed with a heat pump and a thermoelectric generator in a sustainable habitat with an active heat source. Thermal analysis of the system with fluid carrying pipes is carried out using finite element analysis through heat flow and structural analyses. The paper details out some of the important behavioral aspects of a structure-heat exchanger system subjected to thermo-mechanical-fluid load.

## **Small Satellite Solar Thermal Propulsion System Design: Initial Thermal Analysis**

TFAWS2017-IN-06

*Mookesh Dhanasar, William Edmonson, Frederick Ferguson, Leonard Uitenham*

*North Carolina A&T State University, Greensboro, NC*

*Isaiah Blankson*

*NASA Glenn Research Center, Cleveland, OH*

Small satellite technology continues to be an emerging field that is gaining popularity. This paper presents a thermal analysis for the heat-exchanger solar thermal propulsion concept for use on nano—and possibly pico—satellites in Low Earth Orbits (LEO). The proposed heat-exchanger solar thermal propulsion concept attempts to move away from traditional concentrator solar thermal propulsion technologies. Key components in this concept include a solar array heat exchanger, a propellant tank heat exchanger and a radiator. It proposes the use of high temperature solar arrays which can reach temperatures of about 100 °C in LEO, during daytime operations. Heat is removed from the solar array by the use of a heat exchanger arrangement. It is theorized that some of the thermal energy removed is used to heat up the propellant over a 50 - 80 °C temperature range. Excess thermal energy is radiated into space before the heat-exchanger working fluid returns to the solar array. Initial theoretical thrust force and specific impulse values are obtained by the use of established mathematical relations. These mathematical relations produce numerical values that are comparable with other small satellite propulsion concepts, including the traditional concentrator solar thermal propulsion designs, currently under investigations. This phase of the study will address the thermal analysis of the solar array heat exchanger, the propellant heat exchanger, and the radiator. The study will be extended to include the choice of the heat exchanger working fluid and the appropriate flow rates necessary to maintain the prescribed thermal conditions. A small satellite with an on-board propulsion system will expand the capability of these platforms.

## **Thermal Conductance Measurement and Flexibility Enhancement of Flexible Thermal Links**

TFAWS2017-IN-09

*Matt Felt, Matt Sinfield, Brian Thompson, Matt Munns  
Space Dynamics Laboratory / Utah State University*

Flexible thermal links are commonly used in thermal control systems where a thermal connection is required between components that cannot be rigidly connected. Thermal conductance of these components must be measured due to the impact on system power and thermal balance. Thermal conductance tests are performed under vacuum in carefully controlled conditions to minimize parasitic heat. Heat flow through the part is controlled and the temperature drop across the part is measured. A least squares fit line is fit to the test data, the slope of which represents the conductance. The standard error of the conductance is calculated. Test results and error estimates are presented for test temperatures ranging from 35 K to 300 K. These methods are applicable to conductance measurements of any similar conductive hardware. Lessons learned are also presented.

Thermal links made of foils are often stiffer in one axis parallel to the plane of the foils. The flexibility in the stiff axis has been found to improve when using foils that have been slit lengthwise. A load versus deflection test was performed to demonstrate the improvement gained by adding these slits. The test results are presented and discussed.

## **Interdependence of Length, Diameter and Strain States on the Thermal Transport Property of Nanostructures**

TFAWS2017-IN-10

*Sushan Nakarmi  
The University of Alabama, Tuscaloosa, AL  
Vinu Unnikrishnan  
The University of Alabama, Tuscaloosa, AL*

Carbon Nanotubes (CNTs) have excellent thermal transport properties and large aspect ratio which make them ideal for thermal management in nano-electronic devices and composites. The thermal conductivity of nanotube is found to be dependent on the strain state of the nanotube (tensile and compression loading), besides the size (length and diameter). The improved understanding of the effect of these parameters on the thermal characteristics is critical for efficient use in nanoscale applications. The nanotube thermal conductivity is calculated in LAMMPS using Heat-Bath method-a reverse nonequilibrium molecular dynamics (RNEMD) simulation approach. In RNEMD, constant amount of heat is added to and removed from hot and cold regions and the resultant temperature gradient is measured. The AIREBO potential is used for atomic interactions. Preliminary analysis on armchair and zig-zag nanotubes at varying length depicts sharp decrement of thermal conductivity with decrease in length of the nanotube. This is primarily because the length of the system is less than the phonon mean free path (MFP) and is attributed to the ballistic dominant thermal transport phenomenon. For lengths, greater than MFP, the length of nanotube has little effect on its thermal conductivity due to a diffusive-ballistic thermal transport process. Effect of varying chirality and externally applied strain on the thermal properties of the nanostructure will be presented.

## **Effect of Solar Specularity and Ray-Tracing Modeling in NX Thermal Solver on Thermal Analysis of SWOT Mission**

TFAWS2017-IN-11

*Lina L. Maricic*

*ATA Engineering, Inc.*

*Louis A. Tse*

*Jet Propulsion Laboratory, California Institute of Technology*

Jet Propulsion Laboratory's (JPL) Surface Water and Ocean Topography (SWOT) mission is an international mission partnered with Centre National d'Etudes Spatiales (CNES) and Canadian Space Agency (CSA). The SWOT spacecraft will measure both Earth's surface water and the topography of the ocean surface.

In conjunction with JPL, ATA Engineering provided thermal analysis support of the SWOT mission. A wide range of sensitivity analyses have been performed with the SWOT thermal math model. This paper focuses on the sensitivity analysis of solar specularity and ray-tracing modeling options in the Siemens NX thermal solver, and their effect on surface temperatures and thermal stability. A simple model was built in parallel to demonstrate the same effect as seen in the SWOT thermal math model. We found that solar specularity has large impact on temperatures of surfaces that have direct view of the specular surfaces. If specular surfaces are present, ray-tracing is always performed for the direct incident component of solar flux, regardless if the ray-tracing option is specified or not. The ray-tracing option in NX thermal solver is computationally expensive and the added accuracy is minimal. When the ray-tracing option is on, using deterministic or the Monte Carlo method for radiation enclosure view factor calculations generates similar temperature results. Higher element subdivision resolution in deterministic method, or higher number of rays per element in Monte Carlo method, will reduce the resultant difference of the two methods. In our studies, we also found that IR specularity has a smaller impact on surface temperatures than solar specularity.

## **Co-Simulation Modelling of a Medium Sized Thermal Vacuum Facility for Test Feasibility Studies**

TFAWS2017-IN-12

*Matthew Vaughan*

*European Space Agency*

This paper explains the development of a simulation tool to perform feasibility studies for tests inside the medium size TVAC chamber (PHENIX), located at the Test Centre at ESTEC, the European Space Agency's main technological center.

The PHENIX facility consists of a parallelepiped thermal tent mounted inside a vacuum vessel consisting of six independently controlled shrouds, which can achieve temperatures of between -150 to 100 °C in gaseous nitrogen mode or less than -170 °C in liquid nitrogen mode.

The primary purpose of the tool is to determine if a specific test configuration is able to achieve the individually controlled set-point temperatures on the shrouds of the thermal tent. Each shroud is able to remove a given heat flux from the internal environment dependent on the mass

flow rate of gaseous or liquid nitrogen. Radiative interactions inside the tent are also highly coupled and are a function of the size and shape of a test article, resulting in a blockage effect concerning the radiative exchange factors of the shrouds.

Co-simulation is used to model the control and fluidic elements of each shroud using the simulation tool EcosimPro together with a model of the detailed radiative exchanges inside the thermal tent using ESATAN-TMS. The EcosimPro model provides input temperature set points and mixing modes of the gaseous and liquid nitrogen supplies along with the conductive and convective heat transfer along the shroud piping. The ESATAN-TMS thermal model then permits the capture of the detailed pipe network braised to each panel for the heat transfer along the fluid and between the pipes, thermal tent shrouds and test article. This also addresses a secondary purpose of the tool, which is to determine if the calculated shroud temperature homogeneity on a panel is within acceptable limits for a test. The co-simulation models periodically exchange heat flux and temperature data alongside average fluid properties for each shroud.

The tool is designed for use by a discipline non-specialist, therefore it has been integrated into a simple Excel sheet to provide an interface to the model and to perform simulations. The tool is currently in a development stage with further verification planned.

### **Interactive LUROVA™ Thermal Model for the STEM Simulation Game**

TFAWS2017-IN-13

*Ron Creel*

The Apollo Lunar Rover mission support thermal model was introduced at TFAWS-2006, and render engine provided external surfaces for solar heating and radiation modeling parameters were added for an update at TFAWS-2014. Now, the LUROVA™ (LUnar ROVing Adventures) thermal model has been incorporated into a Science, Technology, Engineering, and Mathematics (STEM) simulation game for realistic student challenge and Moon exploration experience. Realism has been improved by using actual lunar terrain data collected since 2009 by the NASA Lunar Reconnaissance Orbiter spacecraft. The LUROVA™ thermal model and simulation game development process will be reviewed, and TFAWS-2017 attendees can try out their lunar exploration skills with the LUROVA™ demonstration in the poster review area.

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## Technical Poster Abstracts

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### **Modeling Radiation Attenuation and Heat Deposition in Propellant from Nuclear Thermal Propulsion with Beer-Lambert Law**

TFAWS2017-Technical Poster 1

*Alexander Aueron*

*The University of Alabama in Huntsville  
Huntsville, Alabama USA*

Liquid Hydrogen (LH2) propellant for Nuclear Thermal Rockets enables high specific impulse (approximately 900 to 1000 seconds). However, the LH2 must be stored below 20 K, challenging for any type of space vehicle. LH2 also has good radiation attenuation properties, potentially useful as radiation shielding, but results in heat addition. Therefore, thermal design needs to balance LH2 heat load with shielding crew from reactor emissions. Aspects of this approach are depicted on the poster.

### **Mars Helicopter Thermal Design**

TFAWS2017-Technical Poster 2

*Stefano Cappucci*

*Jet Propulsion Laboratory, California Institute of Technology  
Pasadena, California USA*

The Mars Helicopter is a technology development project led by Jet Propulsion Laboratory in joint effort with AeroVironment Inc., NASA's Ames Research Center, and NASA's Langley Research Center. An autonomous solar powered helicopter would be able to provide high resolution aerial images of Mars that would allow scientists to discover new geological features and better plan missions for next generation rovers. Aspects of Mars Helicopter thermal design are depicted on the poster.

## **Interactive LUROVA™ Thermal Model for Realistic Student STEM Challenge and Moon Exploration Experience**

TFAWS2017-Technical Poster 3

*Ron Creel*

*NASA Apollo Lunar Roving Vehicle Development and Mission Support Team Member (Retired)  
Huntsville, Alabama USA*

The thermal vacuum test correlated NASA Rover Thermal Math Model (TMM) was used for Apollo 15 mission support. This TMM was reduced for faster mission support response of selected hardware during Apollo Missions 16 and 17, then later combined with Lunar Reconnaissance Orbiter terrain data. Render engine faceting of TMM surfaces, terrain data, and other computer applications led to the development of a Science, Technology, Engineering, and Math (STEM) simulation game that provides the TMM with inputs for planning/preparation, mission timing/location, Rover configuration, power, driving and steering, as well as solar heating and component cool down dust effects. The current version of this STEM tool, the Lunar Roving Adventures (LUROVATM), is discussed by lecture and demonstrated during the poster session.

## **Aircraft Wake Vortex Analysis**

TFAWS2017-Technical Poster 4

*Joel Malissa*

*University of Pennsylvania  
Philadelphia, Pennsylvania USA*

Aircraft wake vortices are a hazard for trailing airplanes and impose constraints on aircraft separation, which result in reduced capacity and efficiency of the National Airspace System. Aircraft separation standards may be safely reduced to enable more optimal use of already saturated airspace with a better understanding of how vortices behave. This poster presents new analytical findings theorized over 20 years ago by Dr. Rowland Bowles at NASA Langley in 1995 concerning vortex-induced rolling moment and lift of a trailing aircraft. The refinements incorporate elliptical wing loading in place of constant loading. Test data from the NASA Ames 80' x 120' wind tunnel validates these results against previous research.

## **Preliminary Thermal Analysis of the X-IFU Radiative Shields Assembly**

TFAWS2017-Technical Poster 5

*Javier Piqueras*

*Universidad Politécnica de Madrid  
Madrid, Spain*

The X-ray Integral Field Unit (X-IFU) radiative shields assembly of the European Space Agency (ESA) Athena was thermally analyzed. Configuration, spacing, and thermal coupling of the four radiative shields, composite mechanical straps, harness, and multi-layer insulation were simulated then parametrically studied for varied temperature regimes. Temperature and heat flux result sensitivity as well as thermal design feasibility were determined, and are depicted on the poster.

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## Speakers

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### **Keynote Speaker: Dr. Tom Crouch**

Senior Curator, Smithsonian National Air and Space Museum  
“The Wright Brothers and the Invention of the Aerial Age”



Dr. Tom Crouch is senior curator, Aeronautics Department, National Air and Space Museum. A Smithsonian employee since 1974, he has served both the National Air and Space Museum and the National Museum of American History in a variety of curatorial and administrative posts. Prior to coming to the Smithsonian he was employed by the Ohio Historical Society as director of education (1969-1973) and as director, Ohio American Revolution Bicentennial Advisory Commission (1973-1974).

Dr. Crouch holds a BA (1962) from Ohio University, an MA (1968) from Miami University and a PhD (1976) from the Ohio State University. All of his degrees are in history. In addition, he holds the honorary degree of Doctor of Humane Letters, conferred in June 2001 by the Wright State University.

He is the author or editor of a number of books and many articles for both popular magazines and scholarly journals. These include: *The Bishop's Boys: A Life of Wilbur and Orville Wright* (New York: W.W. Norton, 1989); *Eagle Aloft: Two Centuries of the Balloon in America* (Washington, D.C.: The Smithsonian Institution Press, 1983); *Wings: A History of Aviation from Kites to the Space Age* (NY: W.W. Norton, 2003); *A Dream of Wings: Americans and the Airplane, 1875-1905* (New York: W.W. Norton, Inc., 1981); *Bleriot XI: The Story of a Classic Airplane* (Washington, D.C.: Smithsonian Institution Press, 1982); *Rocketeers and Gentlemen Engineers* (Reston, Va:



AIAA, 2006), and *Lighter-Than-Air: An Illustrated History of Balloons and Airships* (Baltimore: The Johns Hopkins University Press, 2009).

Dr. Crouch has won a number of major writing awards, including the history book prizes offered by both the American Institute of Aeronautics and Astronautics and the Aviation/Space Writers Association. He received a 1989 Christopher Award, a literary prize recognizing “significant artistic achievement in support of the highest values of the human spirit,” for *The Bishop’s Boys: A Life of Wilbur and Orville Wright*. His book, *Wings: A History of Aviation From Kites to the Space Age*, won the AIAA Gardner-Lasser Literature Prize for 2005, an award presented to the best book selected in that year from all books in the field of aerospace history published in the last five years.

Throughout his career, Dr. Crouch has played a major role in planning museum exhibitions. He was involved in planning exhibitions for the Neil Armstrong Museum, Wapakoneta, Ohio; the Ohio Historical Center, Columbus, Ohio; the National Air and Space Museum; the National Museum of American History; and the Stephen F. Udvar-Hazy Center of the National Air and Space Museum.

In the fall of 2000, President Clinton appointed Dr. Crouch to the Chairmanship of the First Flight Centennial Federal Advisory Board, an organization created to advise the Centennial of Flight Commission on activities planned to commemorate the 100th anniversary of powered flight.

**Tuesday Luncheon Speaker: Garry Lyles**

Space Launch System Program Chief Engineer

“Status of the Space Launch System Program”



Garry Lyles is the Space Launch System’s Chief Engineer, leading the design and development of the nation’s next heavy-lift rocket for human exploration beyond Earth orbit. With more than 40 years technical experience in space propulsion and systems engineering, Garry M. Lyles is considered a top expert. He has been called upon by NASA on numerous occasions to lead organizations through dramatic change because he demonstrated the ability to provide a clear course and focus on the desired end results. Previously, Garry was the Technical Associate Director of the Marshall Space Flight Center’s Engineering Directorate.

Garry has received the highest honors given for commitment to excellence in public service, including the Presidential Rank of Distinguished Executive Award. He received the Astronautics Engineer Award from the National Space Club in honor of his decades of engineering management for the nation’s human space flight systems.

Garry holds a bachelor’s degree in mechanical engineering from the University of Alabama and he was inducted into its class of Distinguished Engineering Fellows in 2010.

### **Wednesday Luncheon Speaker: Les Johnson**

Technical Assistant Advanced Concepts Office

“Advanced In-Space Propulsion Technologies for Exploring the Solar System and Beyond”



Les Johnson is a physicist and works in the Science and Technology Office at the NASA George C. Marshall Space Flight Center. He is the Solar Sail Principal Investigator for the NASA Near-Earth Asteroid Scout mission, a Co-Investigator for the European InflateSail solar sail demonstration mission, and the JAXA T-Rex space tether experiment. Les has also served as the Technical Assistant for the Advanced Concepts Office and the Manager for the Space Science Programs and Projects Office, the In-Space Propulsion Technology Program, and the Interstellar Propulsion Research Project. He thrice received NASA's Exceptional Achievement Medal and has 3 patents. He is a member of the American Institute of Aeronautics and Astronautics, the National Space Society, The British Interplanetary Society and MENSA.

Les is an author of several popular science books including “Solar Sails: A Novel Approach to Interplanetary Travel” and “Harvesting Space for a Greener Earth.” He is also a science fiction writer; with NYT bestselling author Ben Bova, he coauthored, “Rescue Mode,” a novel about near-term human Mars exploration. Les received his BA in chemistry and physics from Transylvania University (Lexington, KY) and his MS in physics from Vanderbilt University (Nashville, TN).

**Thursday Luncheon Speaker: Graham Nelson**

**“Liquid Propulsion Systems Additive Manufacturing”**



Graham Nelson has been at the NASA Marshall Space Flight Center since 2007, when he hired in to the Thermal and Combustion Analysis Branch. He spent 7 years in the thermal branch, where he provided design and analyses support on a wide range of products, including both solid rocket motors and liquid rocket engines. Graham has spent the last 3 years in the Liquid Engine Systems branch, where he is currently serving as project lead for the Additive Manufacturing Demonstrator Engine – an effort that is centered around advancing additively manufactured technologies for liquid rocket engine applications. Graham received his Bachelor of Science in Mechanical Engineering from the University of Tennessee, Knoxville and a Master of Science in Mechanical Engineering from the Georgia Institute of Technology.

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## TFAWS Tours 2017

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Site tours of NASA Marshall Space Flight Center will be available to those that registered and were confirmed for the tour, directly following lunch on the afternoon of Tuesday, August 22, and Friday morning, August 25. (<https://www.nasa.gov/centers/marshall/home/index.html>)

### **West Test Area**

Built in the 1960s, the West Test Area has been used for hundreds of test firings in support of the U.S. space program. The Saturn V rocket's first-stage engine, the F-1, and Space Shuttle Main Engines have been tested there. Two new structural test stands for the Space Launch System are currently being finished. These test stands will subject the liquid Hydrogen and Oxygen tanks to the same loads and stresses they will endure during launch.

(<https://www.nasa.gov/centers/marshall/news/news/releases/2017/construction-complete-stand-prepares-to-test-sls-s-largest-fuel-tank.html>)



## **East Test Area**

Built in the 1950s and 1960s, the East Test Area was designed to develop and test various missiles and rockets, beginning with the Redstone rocket. Hundreds of tests have been conducted there on rocket engines, as well as the Space Shuttle and the Saturn I and Saturn I-B rockets. The refurbished Hot Gas Test Facility located here, which generates flow speeds up to Mach 4 and high heat rates to test materials and coatings.

## **The Payload Operations Integration Center (POIC)**

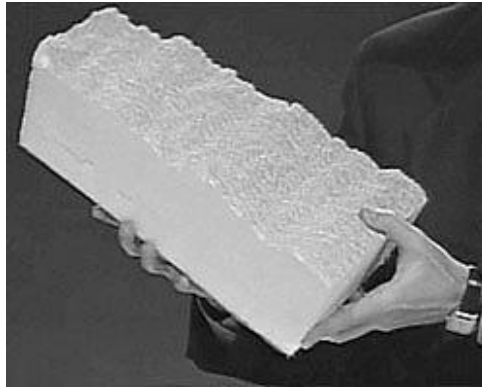


Located within the HOSC at Marshall, is the primary NASA ground system responsible for integrated operational payload flight control and planning for the ISS. It provides payload telemetry processing, command uplink, and planning capabilities for a large number of local Cadre flight controllers and remote ISS payload users and other facilities located throughout the world. The POIC provides a secure integration point for planning all ISS operations. (<https://www.nasa.gov/centers/marshall/earthorbit/ops.html>)

## **Environmental Test Facility (ETF)**

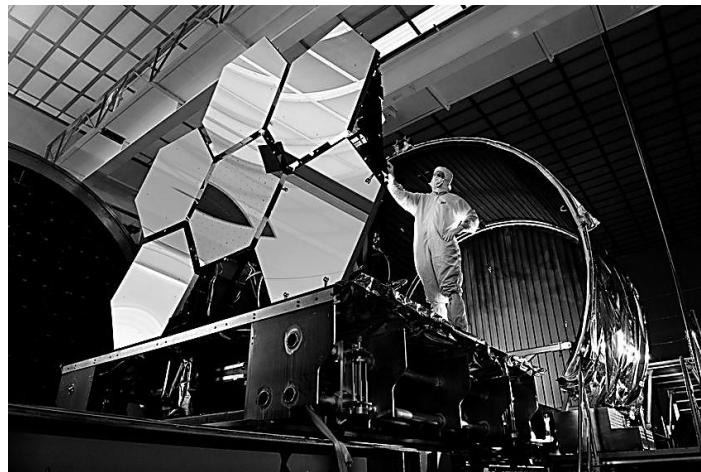
Marshall's ETF provides various environments allowing a customer to test and qualify hardware prior to launch. The environments include the vacuum environment of space, the in-cabin environment of spacecraft and the natural environment seen by a vehicle on the pad prior to launch.

## **Thermal Protection System (TPS) Development Facility**



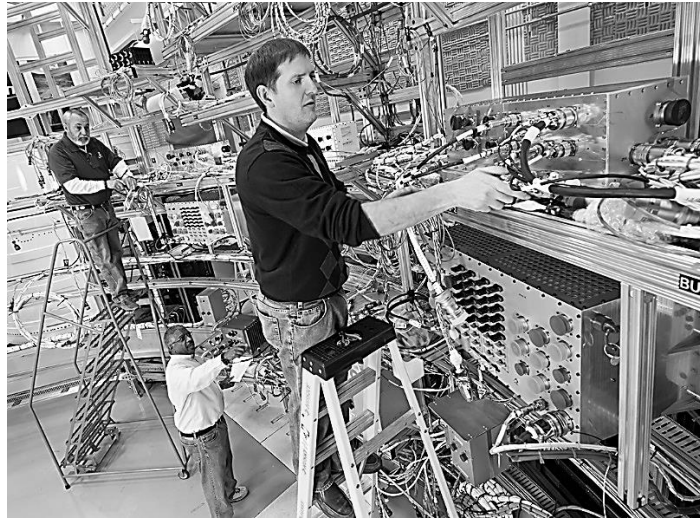
The TPS Development Facility is used to characterize materials and provide data on equipment and processing parameters to support large-scale TPS applications. The Facility provides the ability to apply both primers and spray on foam insulation (SOFI) materials to large-scale test articles in various orientations.

## **X-ray and Cryogenic Facility (XRCF)**



XRCF is an adaptable space environment simulation facility that has been enabling technology development and pre-flight verification of space missions since 1991. As the Agency's premier cryogenic optical test facility, the XRCF enables the development and pre-flight evaluation of large direct-incidence telescope mirrors and structures in relevant thermal environments to 20 Kelvin. As the world's largest x-ray optical test facility, the XRCF enables development, performance, and calibration testing of grazing-incidence x-ray optics, detectors and telescopes. The facility's capability has been utilized in the development and verification activities of NASA flagship missions such as the Chandra X-ray Observatory ([https://www.nasa.gov/mission\\_pages/chandra/main/index.html](https://www.nasa.gov/mission_pages/chandra/main/index.html)) and the James Webb Space Telescope ([https://www.nasa.gov/topics/universe/features/mirror\\_chill.html](https://www.nasa.gov/topics/universe/features/mirror_chill.html))

## **SLS System Integration Lab (SIL) and Thrust Vector Control (TVC) Test Lab**



The SIL and the TVC Test Lab provide integrated test environments for the Space Launch System's flight software and avionics hardware. SIL supports end-to-end integrated avionics and software integration, check-out, verification, and validation. The Thrust Vector Control Test Lab supports the development, certification and qualification testing of control mechanisms, primarily Thrust Vector Control (TVC) actuators and systems. The SIL and the TVC Lab can also be integrated together to develop and test multiple components of avionics and software to provide an even more comprehensive early integration to support programs and projects.

## **Propulsion Research Lab**



Engineers and Researchers use this facility to conduct state-of-the-art prototyping and experimental activities investigating a wide range of technologies including nuclear thermal and electric propulsion, pulsed high power system for plasma/fusion propulsion, cryogenic fluid management and launch/in-space vehicle systems.



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## Vendor Booth Participation

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Advanced Cooling Technologies  
Aerothreads, Inc.  
ANSYS  
Beta CAE Systems USA, Inc.  
COMSOL, Inc.  
CRTech  
Gamma Technologies  
Genesis Engineering Solutions  
JANNAF  
LoadPath  
Maya Simulation Technologies  
Mentor  
Roush Advanced Engineering  
Spacedesign Corporation  
Tecplot  
ThermoAnalytics

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Aerosciences – David Schuster

TFAWS 2017 Chair: Callie McKelvey

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Matthew Cross

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Darrell Davis

Brian Evans

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Carlos Gomez

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Analysis Branch

MSFC ER43 Thermal and Combustion  
Branch

MSFC EV33 Aerosciences Branch

MSFC EV34 Thermal Analysis and  
Control Branch

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